AWS D17.1/D17.1M:2017
An American National Standard

Specification for Fusion Welding for Aerospace Applications

American Welding Society®

Approved American National Standard
ANSI

AWS D17.1/D17.1M:2017
An American National Standard

Approved by the
American National Standards Institute
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Specification for Fusion Welding for Aerospace Applications

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Prepared by the
American Welding Society (AWS) D17 Committee on Welding in the Aircraft and Aerospace Industries

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This specification provides the general welding requirements for welding aircraft and space hardware. It includes but is not limited to the fusion welding of aluminum-based, nickel-based, iron-based, cobalt-based, magnesium-based, and titanium-based alloys using electric arc and high energy beam processes. There are requirements for welding design, personnel and procedure qualification, inspection, and acceptance criteria for aerospace, support, and non-flight hardware. Additional requirements cover repair welding of existing hardware. A commentary for the specification is included.

American Welding Society®

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Foreword

This foreword is not part of this standard but is included for informational purposes only.

Prior to 1977, aviation welding specifications were primarily dependent on government standards for contract purchases and were based on welding technology from the 1950s. Those specifications were MIL-W-8611 (steel), MIL-W-8604 (aluminum), MIL-W-18326 (magnesium), and MIL-T-5021 for welder performance requirements. In 1977, the aviation and aerospace industry and government moved to update some of these standards by consolidating the welder's performance of MIL-T-5021 into MIL-STD-1595. MIL-STD-1595 was issued as a supplement to the ASME Section IX code in 1977. It was subsequently revised and superseded by MIL-STD-1595A in 1983. The first update to the 1950's welding process specifications came with the release of MIL-W-8604A in 1982, almost 30 years after its initial release. The material welding specifications MIL-W-8604, MIL-W-8611, and MIL-W-18326 were consolidated into MIL-STD-2219 in 1988 and represented the most significant change to aviation welding standards in more than 30 years.

After two unsuccessful attempts to change the military standards, the American Welding Society contacted the industry and proposed a meeting to develop a national specification. Interested welding personnel from the aviation industry gathered together in the autumn of 1993 to lay the foundation for a national aviation and aerospace specification for fusion welding to replace MIL-STD-1595A and MIL-STD-2219. This meeting led to the formation of the AWS D17 Committee on Welding in the Aircraft and Aerospace Industries. The overriding theme the welding committee members brought to the table was that the aviation industry had changed. Those changes affected the welding processes and procedures, base metal and filler metal types, quality, and the inspection equipment, just to name a few. Since the 1950s, the welding specifications had not completely kept pace during the revision process to reflect those technology changes. The writing of this specification was a prime opportunity for the industry and government to create a document to include those changes. Through an industrial effort and committee consensus, this specification represents several years of work, bringing the aviation and aerospace industry together to acknowledge the technological advances of welding and materials. Included in this document is weld repair technology to enable the use of weld repair beyond those areas originally designated for a weld.

Changes to this third edition of D17.1 include the following:

(1) Removed Annex B—Effective Throat of 2010 edition

(2) Added Annex D—Materials in Table 5.4 with cross-referenced UNS numbers to [proprietary tradenames].

(3) Added Annex G—Samples of Welding Forms for WPSs, PQRs, and Welder Performance Qualifications by removing the samples from elsewhere in the standard.

(4) Added Annex H—Qualified Positions for Production Welding

(5) Added Annex I—Common Acronyms Used in this Standard for quick user reference.

(6) Added Figures 5.11C and 5.11D to the standard.

(7) Separated Table B.3 into B.3 and B.3M, one for U.S. Customary Units and one for the International System of Units.

(8) Conversion values were updated to reflect AWS A1.1, *Metric Practice Guide for the Welding Industry.*

Underlined areas in text indicate an addition and vertical lines adjacent to text, figures, tables, and equations indicate where changes (additions, modifications, corrections, deletions) from the 2010 edition were made.

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Specification for Fusion Welding for Aerospace Applications

1. General Requirements

1.1 Scope. This specification contains requirements for fusion welding and non-destructive examination (NDE) of aerospace flight hardware as well as for the welding and NDE of non-flight hardware. When this specification is stipulated in contract documents, conformance with all provisions of the specification shall be required, except for those provisions specifically exempted or modified by the Engineering Authority or contract documents.

The following is a summary of the specification clauses:

Clause 1. **General Requirements**: basic information on the scope and provisions of this specification.

Clause 2. **Normative References**: a listing of the documents that are required for the application of this specification.

Clause 3. **Terms and Definitions:** a list of technical terms and definitions of particular importance to this specification.

Clause 4. **Design of Welded Connections**: requirements and guidance information for the design of welded connections.

Clause 5. **Welding Procedure and Performance Qualification**: qualification requirements for welding procedures, welders, welding operators, and tack welders.

Clause 6. **Fabrication**: requirements for preparation, assembly, and workmanship when welding aerospace hardware.

Clause 7. **Inspection**: criteria for inspector qualification, responsibilities of inspectors, acceptance of production welds, and standard requirements for performing visual inspection and nondestructive examination (NDE).

Clause 8. **Repair of Existing Structures**: requirements for repair of existing aerospace flight hardware.

Clause 9. **Nonflight Hardware**: requirements for welding nonflight hardware.

1.1.1 Flight Hardware. The purpose of this specification is to provide requirements for commonly used fusion welding processes, materials, and acceptance criteria for production welds. This specification also provides requirements for materials, processes, and acceptance criteria that are not listed in this specification when approved by the Engineering Authority.

1.1.1.1 Aircraft, Rotorcraft, and Engines Subject to Federal Aviation Administration (FAA) Regulation. When applying welding in the design, construction, and repair of aircraft, rotorcraft, or engines subject to FAA regulation, the Engineering Authority must perform the appropriate design analyses and impose process control measures that will ensure compliance with the applicable requirements of the Code of Federal Regulations, Title 14.

1.1.2 Nonflight Hardware. Nonflight hardware, tooling, ground support equipment, and related nonconventional aerospace facilities shall be designed and welded in accordance with the requirements of Clause 9.

1.2 Units of Measure. This standard makes use of both U.S. Customary Units and the International System of Units (SI). The latter are shown within brackets ([ ]) or in appropriate columns in tables and figures. The measurements may not be the exact equivalents; therefore, each system must be used independently.

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard and therefore are not addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

(2) AWS Safety and Health Fact Sheets

(3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

(1) Safety Data Sheets supplied by materials manufacturers

(2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

1.4 Classification. All welds produced in accordance with this specification shall be classified on the engineering drawings or contract. Weld classifications shall be as follows: Class A, Class B, or Class C. These classifications refer to the level of inspection required and to the applicable acceptance criteria. Alternate acceptance criteria and inspection methods shall be applied if specified on the engineering drawing. A weld joint may be zoned with multiple classifications.

1.4.1 Procedure Qualification Criteria. The Engineering Authority shall determine the welding procedure qualification requirements for all classifications in accordance with Clause 5 (see Annex F—Commentary). Alternate procedure qualification acceptance criteria may be used when specified on the engineering drawing.

1.5 Approval. All references to the need for approval shall be interpreted to mean approval by the Customer or the Engineering Authority.

1.6 Mandatory Provisions and Authority. Nothing in this specification supersedes applicable laws and regulations unless a specific exemption has been obtained prior to the contract date or as a contract amendment.

1.6.1 Mandatory Provisions. Most provisions of this specification are mandatory when the use of this specification is invoked. Certain provisions are optional and apply only when specified in contractual documents for a specific project. Guidance information is indicated by the words "should" or "may."

1.6.2 Drawing Authority. When requirements in this specification conflict with those on the engineering drawing, the requirements on the engineering drawing shall take precedence.

1.6.3 Specification Authority. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification takes precedence.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.1 Government Documents

Federal and Military Specifications, Standards, and Handbooks:

Code of Federal Regulations, *Title 14, Aeronautics and Space*.

2.2 Nongovernment Documents

American Welding Society (AWS) documents:

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination;*

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*;

AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*;

AWS B4.0, *Standard Methods for Mechanical Testing of Welds;*

AWS B5.2, *Specification for the Qualification of Welding Inspectors Specialists and Welding Inspector Assistants;*

AWS QC1, *Standard for AWS Certification of Welding Inspectors*

Aerospace Industries Association (AIA) document:

NAS 410, *NAS Certification & Qualification of Nondestructive Test Personnel*.

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.

American Society for Testing and Materials (ASTM) documents:

ASTM E164, *Standard Practice for Ultrasonic Contact Testing of Weldments*;

ASTM E1417M, *Standard Practice for Liquid Penetrant Testing;*

ASTM E1444M, *Standard Practice for Magnetic Particle Testing*;

ASTM E1742M, *Standard Practice for Radiographic Examination*;

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.*

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions,* provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document. Refer to Annex I for a list of commonly used acronyms in this standard.

aerospace flight hardware. Any portion of a flight vehicle (e.g., aircraft, missile, spacecraft) or its payload.

complex weld joint. A continuous weld joint with variations in section thickness and tapered transitions that may require changes in welding position or direction, weld deposition rates, and heat inputs during the execution of a weld. A complex weld joint cannot be defined on the engineering drawing by a single welding symbol.

critical structure. A structure or component in which a single failure would cause significant danger to personnel, loss of system, loss of major component, loss of control, unintentional release of critical stores, inability to release armament stores, result in an operating penalty or loss of the aerospace system, or abortion of the mission.

customer. The individual or organization which established the mission or design requirements of a product and provides some form of compensation for the delivery of the product. The product could be an engineering design, a structure, a system, or a weldment.

Engineering Authority. The Engineering Authority is the contracting agency or corporate organization that acts for and on behalf of the customer on all matters within the scope of this standard. The Engineering Authority has the responsibility for the structural integrity or maintenance of airworthiness of the hardware and compliance with all contract documents.

fabricator. The organization responsible for producing weldments that satisfy the design and contract requirements.

fail safe. A part is defined as fail safe if it can be shown by analysis or test that, due to structural redundancy, the structure remaining after failure of the one part can sustain the new limit loads with an ultimate factor of safety equal to or greater than 1.0, and the remaining structure has sufficient fatigue life to complete the mission.

filler alloy type. A recognized designation of a nominal alloy composition from a recognized industry organization (examples AA4043, ER321, Ti-6Al-4V).

fracture critical. A part which, by fracture mechanics analysis, has a service life factor of less than an engineering-defined factor times the vehicle life cycle requirements and failure of which would cause loss of the mission, vehicle, or crew. Also, a part that is a pressure vessel or a rotating machinery component.

Material Review Board (MRB). A customer or Engineering Authority activity to review and formally disposition non-conforming hardware. MRB typically has the authority to take exception to engineering requirements, which includes authorizing repairs.

nonconventional aerospace facilities. Nonconventional aerospace facilities are program-oriented or experimental in nature and may include, but not be limited to, launch complexes, test stands, wind tunnels, operational or research facilities, towers, and similar special purpose facilities whose structures are characterized by unusual or inadequately defined loading conditions, a lack of design precedent, or frequent modifications to support changes in the operational requirements.

noncritical structure. A structure or component which is noncritical and is contained so that failure will not affect other flight elements or personnel.

nonstandard materials. Base metals and/or filler metals not covered by industrial welding codes or specifications.

qualification variable. One of a set of elements that define the qualification limits of a welding procedure specification or of welders/welding operators/tack welders.

safety critical item. A component whose failure will result in probable loss of the aircraft or hazard to personnel due to direct part failure or by causing other progressive part failures.

semicritical structure. A structure or component, the single failure of which would reduce the overall efficiency of the system, but a loss of the system or danger to personnel would not be experienced.

structures. Structures are defined by the Engineering Authority according to accepted practices and shall have the same meaning herein.

UNS number. The Unified Numbering System (UNS) is a composition-based system of commercial materials. Each metal is indicated by a letter that is followed by five numbers.

4. Design of Welded Connections

4.1 Scope. The Engineering Authority shall design the weldment and define the requirements to ensure compliance with all mission and systems requirements. The engineering documentation shall clearly define special requirements, such as fracture critical, or safety critical, imposed over and above the general requirements. Further, the Engineering Authority shall define process controls and substantiate that all design requirements can be met by welds produced in accordance with specified procedure, fabrication, and inspection requirements. Annex A contains further guidance on the weld joint design and analysis.

4.2 Weldment Design Data. The Engineering Authority shall develop or obtain appropriate material property data to support the weldment design. In addition, the weldment design shall either account for the residual stresses resulting from the welding process or the Engineering Authority shall provide an appropriate method for controlling/minimizing those residual stresses, such as annealing or aging after welding.

4.3 General Drawing Requirements

4.3.1 Drawing Information. Essential information for all welds shall be completely described on the engineering drawing or in referenced supporting documentation. When necessary, the engineering drawing shall show the profile (cross section) of a complex weld joint with sufficient detail for the fabricator to determine essential features at any position along the length of the weld.

4.3.2 Groove Welds. All groove welds, including those in flanged butt and corner joints, shall be full penetration (complete joint penetration) unless otherwise specified on the engineering drawing or in the referenced supporting documentation.

4.3.3 Fillet Welds. Fillet weld size shall be specified on the engineering drawing. Unless otherwise indicated, the specified size is a minimum with the default maximum size listed in Table 7.1. Fillet weld root penetration shall not be included in weld strength calculations unless a combination groove and fillet weld is specified for the joint.

4.3.4 Essential Information. For all welds, the engineering drawing or referenced supporting documents shall specify this specification and the following:

(1) base metal type and condition at the time of welding (e.g., annealed, normalized, etc.)

(2) filler metal type, composition or autogenous weld (without filler)

(3) postweld thermal treatment, method, or heat treatment cycles (including tensile strength or hardness values as applicable)

(4) welding symbols per AWS A2.4

(a) weld location and extent of welding

(b) final weld contour and weld finishing requirements (as welded or subsequently finished)

(c) Special conditions shall be fully explained by added notes or details on the engineering drawing.

(5) weld classifications (Class A, B, or C)

(6) weld sequence and technique when necessary to control shrinkage stresses and distortion

(7) dimensional controls required to assure final drawing dimensions

(8) alternate inspection methods and acceptance criteria where applicable.

NOTE: Unless indicated otherwise, dimensions on the weldment drawing indicate the final dimensions of the weldment and do not include allowances for shrinkage.

4.3.5 Inspection Requirements. The engineering drawings shall define weld inspection requirements. Clause 7 specifies default inspection requirements based on classification, which may be modified as appropriate. Those requirements may be modified as appropriate. A single weld may utilize more than one set of inspection requirements through the use of separate zones applied to the weld.

5. Welding Procedure and Performance Qualification

5.1 General. This clause establishes the requirements for welding procedure specification data (WPS), welding procedure qualification, and welder/welding operator/tack welder performance qualification. It also contains provisions for maintenance of welder/welding operator/tack welder qualification.

5.1.1 Content and Format of Welding Documents. The WPS, procedure qualification record (PQR), and welder/welding operator/tack welder certification shall contain all the required data to appropriately characterize the welding procedure, record of procedure qualification, and record of welder or welding operator qualification. The specific format is optional. Sample forms are shown in Annex G. In all cases, it is the responsibility of the fabricator to ensure that all required data and welding information is included on all welding documents and records.

5.1.2 Previously Qualified Welding Procedures and Welders/Welding Operators. WPSs, PQRs, and welder/welding operator certifications that were written and qualified to previous editions of this specification need not be revised or requalified, within the limits specified herein.

5.2 Welding Procedure Data and Qualification

5.2.1 Written WPS. All welds produced to the requirements of this specification shall be accomplished in accordance with a written WPS. A WPS shall include the welding data shown in Table 5.1 for the relevant welding process.

NOTE: The WPS may list variables recorded on the PQR within the full range permitted for a qualification variable and practical limits determined by the fabricator for non-qualification variables.

5.2.2 Qualification of Welding Procedures. WPSs for Class A and B welds shall have a supporting PQR. WPSs for Class C welds and tack welds do not require a supporting PQR. Welders or welding operators that successfully complete the procedure qualification, as stated in 5.3.3, shall concurrently be given their performance qualification for that activity. With the approval of the Engineering Authority, AWS B2.1 may be used for welding procedure qualification.

5.2.2.1 Standard Method of Welding Procedure Qualification. The WPS shall be qualified in accordance with the requirements specified by the Engineering Authority. If the Engineering Authority has not specified requirements for WPS qualification, the WPS shall be qualified in accordance with this specification by performing a welding procedure

test weldment and recording the actual values on a PQR. The qualification variables for a welding procedure qualification test weld are as shown in Table 5.2 for each of the welding processes. A change in a welding procedure variable beyond the limits shown in Table 5.2 requires a new procedure qualification.

5.2.2.2 Test Methods for WPS Qualification.

(1) See Figures 5.5, 5.6, 5.7, and 5.8 for test coupon configuration.

(2) Test welds shall be inspected and accepted or rejected in accordance with the methods and acceptance criteria for the class of weld to be qualified per Table 7.1, except a 0.5 in [13 mm] discard may be taken at the ends of groove and fillet weld coupons in sheet or plate.

(3) Unless otherwise specified by the Engineering Authority, the tests listed in Table 5.3 are required for welding procedure qualification.

(4) When mechanical testing is required by Table 5.3, see AWS B2.1 for the test weldment and required number of test specimens.

(5) The test results shall be recorded on the PQR.

(6) See 5.4.8.2 for acceptance criteria for metallographic examination.

(7) See 5.4.8.3 for acceptance criteria for bend testing.

5.2.2.3 Alternate Methods of Procedure Qualification. In lieu of Clause 5.2.2.1, alternate procedure qualification shall be accomplished. The following provides examples of alternate configurations for procedure qualification:

(1) A simulated weld joint sample.

(2) An actual part.

(3) An applicable qualification test weld.

(4) A special test weldment.

(a) Simulated service test weldment.

(b) Prototype structural special test weldments.

(c) Non-loaded special test weldments.

The Engineering Authority shall specify the test weldment configuration, the test methods, and acceptance criteria for the test weldments to be used when qualifying weld procedures using these alternate methods. Special test weldments as described in AWS B2.1 are not allowed.

Table 5.1
Welding Procedure Specification (WPS) Data

	EBW	FCAW	GMAW	GTAW	LBW	OFW	PAW	SMAW
JOINT DESIGN								
Joint type and dimensions	X	X	X	X	X	X	X	X
Treatment of backside, method of gouging/preparation	O	O	O	O	O	O	O	O
Backing material, if used	O	O	O	O	O	O	O	O
BASE METAL								
Base metal and associated group number per Table 5.4, when applicable	X	X	X	X	X	X	X	X
Thickness range qualified	X	X	X	X	X	X	X	X
Diameter (tubular only)	X	X	X	X	X	X	X	X
The coating description or type, if present	O	O	O	O	O	O	O	O
Base metal M-number for M-1, per Table 5.2	X	X	X	X	X	X	X	X
FILLER METAL								
Specification, classification, or, if not classified, the nominal composition (see Tables 6.4, 6.5, and 6.6)	O	O	O	O	O	O	O	O
Filler metal size or diameter	O	O	O	O	O	O	O	O
Penetration enhancing flux				O				
Supplemental filler metal	O	O	O	O	O		O	
Filler metal feed rate	O	O	O	O	O		O	
Consumable insert and type				O			O	
Supplemental deoxidant	O				O			
Hot filler metal				O			O	
POSITION								
Welding position(s)	X	X	X	X	X	X	X	X
Progression for vertical welding	X	X	X	X	X	X	X	X
PREHEAT AND INTERPASS TEMPERATURE								
Preheat minimum (see Table 6.3)	O	O	O	O	O		O	O
Interpass temperature maximum (if applicable)	O	O	O	O	O		O	O
Preheat maintenance	O	O	O	O	O		O	O
POST WELD HEAT TREATMENT								
PWHT temperature and time	O	O	O	O	O	O	O	O
SHIELDING GAS								
Torch shielding gas and flow rate range		X	X	X	X		X	
Root shielding gas and flow rate range				X	X		X	
Environmental shielding and vacuum pressure	X				X			

(Continued)

Table 5.1 (Continued)
Welding Procedure Specification (WPS) Data

	EBW	FCAW	GMAW	GTAW	LBW	OFW	PAW	SMAW
ELECTRICAL								
Current (or wire feed speed, not required for manual welding), current type, and polarity or power level	**X**	**X**	**X**	**X**	**X**		**X**	**X**
Voltage range (except not required for manual welding)	**X**	**X**	**X**	**X**			**X**	
Beam focus, current, pulse frequency range, and filament type, shape, and size	**X**				**X**			
Specification, classification, and diameter of tungsten electrode				**X**			**X**	
Transfer mode		**X**	**X**					
Pulsed current parameters, if applicable		**O**	**O**	**O**			**O**	**O**
Contact tube to work distance		**X**	**X**					
OTHER WELDING PROCESS VARIABLES								
Welding process and whether manual, semiautomatic, mechanized, or automatic	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
For mechanized or automatic, single or multiple electrode and spacing	**X**	**X**	**X**	**X**			**X**	
Single or multipass	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Cleaning method, tools, and/or agents	**X**	**X**	**X**	**X**	**X**		**X**	**X**
Peening		**O**	**O**	**O**			**O**	**O**
Conventional or keyhole technique	**X**				**X**		**X**	
Standoff distance for mechanized and automatic welding	**X**				**X**		**X**	
Stringer or weave bead		**X**	**X**	**X**			**X**	**X**
Travel-speed range for mechanized or automatic welding and manual applications requiring heat input calculations	**X**	**X**	**X**	**X**	**X**		**X**	
Fuel gas and flame type (oxidizing, neutral, carburizing)						**X**		

X – Data that shall be included in a WPS.
O – Data that only need be included in a WPS if used for that particular welding procedure.

Legend:

Fusion Welding Processes:

OFW—Oxyfuel welding
SMAW—Shielded metal arc welding
SAW—Submerged arc welding
GTAW—Gas tungsten arc welding
GMAW—Gas metal arc welding
FCAW—Flux cored arc welding
PAW—Plasma arc welding
EBW—Electron beam welding
LBW—Laser beam welding

Table 5.2
Procedure Qualification Variables

	EBW	FCAW	GMAW	GTAW	LBW	OFW	PAW	SMAW
JOINT DESIGN								
A change in the groove weld type (V-groove, U-groove, Single bevel, etc.)	**Q**				**Q**			
A change from a fillet to a groove weld	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
The addition or deletion of non-fusing metal or non-metallic backing or backing gas				**Q**	**Q**		**Q**	
An increase in the fitup gap beyond that used in the qualification test	**Q**				**Q**			
BASE METAL								
A change in the base metal thickness beyond the range specified below: A test weld with a base metal thickness of t shall qualify welds in base metals with a thickness range of 1/2t to 2t, except when the test weld base metal thickness is equal to or greater than 1 in [25 mm], the qualification range is 1/2t to unlimited. Two test welds shall qualify welds with all intermediate base metal thicknesses	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
A change from one base metal alloy to a different base metal alloy, except a change from one alloy to another within M-1[a]	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
FILLER METAL								
A change in the filler metal alloy type	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
For surfacing, a change in the chemical composition of the weld metal. Each layer shall be considered independent of other layers		**C** **H**	**C** **H**	**C** **H**		**C** **H**	**C** **H**	**C** **H**
A change in the diameter of filler metal added of ±20%	**Q**				**Q**			
The addition or deletion of filler material	**Q**			**Q**	**Q**		**Q**	
A decrease in thickness or a change in the nominal chemical composition of surfacing or buttering beyond that qualified	**C** **H**	**C** **H**	**C** **H**	**C** **H**	**C** **H**	**C** **H**	**C** **H**	**C** **H**
A change of filler metal/electrode nominal size/shape in the first layer		**C** **H**	**C** **H**					**C** **H**
Addition or deletion of supplementary filler metal (powder or wire), or a change of 10% in the amount	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
A change from single to multiple supplementary filler metal or vice versa		**C** **H**	**C** **H**	**C** **H**	**C** **H**	**C** **H**	**C** **H**	

(Continued)

Table 5.2 (Continued)
Procedure Qualification Variables

	EBW	FCAW	GMAW	GTAW	LBW	OFW	PAW	SMAW
Addition or deletion, or a change in the nominal amount or composition of supplementary metal (in addition to filler metal) beyond that qualified			**Q**	**Q**				
The addition or deletion, or a change in the nominal amount or composition of supplementary deoxidation material beyond that qualified	**Q**				**Q**			
POSITION								
The addition of a welding position, except that positions other than flat also qualify for flat		**C** **H**	**C** **H**	**C** **H**		**C** **H**	**C** **H**	**C** **H**
PREHEAT AND INTERPASS TEMPERATURE								
A decrease in preheat of more than 100°F [56°C] from that qualified	**Q**	**Q**	**Q**	**Q**	**Q**		**Q**	**Q**
An increase of more than 100°F [56°C] in the maximum interpass temperature from that recorded on the PQR	**Q**	**Q**	**Q**	**Q**	**Q**		**Q**	**Q**
For heat-treatable materials, an increase in the preheat or interpass temperature of more than 100°F [56°C] from that qualified			**Q**	**Q**			**Q**	**Q**
POST WELD HEAT TREATMENT								
A separate PQR is required for no PWHT and PWHT	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
The qualification test weldment shall be subjected to heat treatment essentially equivalent to that of the production weldment, including at least 80% of the aggregate time at temperature	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
SHIELDING GAS								
The addition or deletion of backing gas				**Q**	**Q**		**Q**	
Addition or deletion of torch shielding gas		**Q**	**Q**	**Q**	**Q**		**Q**	
A change in the specified nominal composition of shielding gas		**Q**	**Q**	**Q**	**Q**		**Q**	
A change of shielding environment from vacuum to an inert gas or vice versa	**Q**				**Q**			
An increase of the vacuum chamber pressure	**Q**							
For titanium and zirconium base metal, a change in the nominal composition, or a decrease of 15% or more in the root shielding flow rate			**Q**	**Q**	**Q**		**Q**	

(Continued)

Table 5.2 (Continued)
Procedure Qualification Variables

	EBW	FCAW	GMAW	GTAW	LBW	OFW	PAW	SMAW
For aluminum, an increase of 50% or more, or a decrease of 20% or more in the shielding gas flow rate used for qualification			**Q**	**Q**	**Q**		**Q**	
For titanium and zirconium base metal, the deletion of, or a change in composition of, or a decrease exceeding 10% in the trailing gas flow rate			**Q**	**Q**	**Q**		**Q**	
The addition, deletion, or a 5% flow rate change for any gas used in the process, or a change in the orientation of the plasma removing gas jet relative to the workpiece (e.g., coaxial transverse to beam)					**Q**			
ELECTRICAL CHARACTERISTICS								
A change exceeding ±2% in the voltage from that qualified	**Q**							
A change from DC to AC and vice versa				**Q**				
A change from DCEN to DCEP and vice versa				**Q**				
A change exceeding ±5% in the beam or beam focus current from that qualified	**Q**							
A change in the beam pulsing frequency or duration from that qualified	**Q**							
A change in filament type, size, or shape	**Q**							
A change in the mode of metal transfer from short circuiting to globular, spray, or pulsed and vice versa		**Q**	**Q**					
OTHER VARIABLES								
A change in welding process	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**	**Q**
A change from multipass per side to single pass per side		**Q**	**Q**	**Q**	**Q**		**Q**	**Q**
A change from stringer bead to weave bead for manual welding		**C** **H**	**C** **H**	**C** **H**			**C** **H**	**C** **H**
A change from a stringer to a weave bead, but not vice versa, for heat-treatable aluminum materials			**Q**	**Q**			**Q**	
A change in the type of fuel or type of flame						**Q**		
OTHER MECHANIZED OR AUTOMATIC WELDING VARIABLES								
A change in distance of ± 2% of the lens focal length					**Q**			

(Continued)

Table 5.2 (Continued)
Procedure Qualification Variables

	EBW	FCAW	GMAW	GTAW	LBW	OFW	PAW	SMAW
A change of greater than ± 10% of the distance between the welding head and the workpiece		**Q**	**Q**	**Q**			**Q**	
A change of travel speed of more than ± 5% or ± 0.5 inch [13 mm] per minute, whichever is greater	**Q**			**Q**	**Q**		**Q**	
A change of travel speed of more than ± 10% or ± 1.0 inch [25 mm] per minute, whichever is greater		**Q**	**Q**					
A change in amperage of ± 5% or ± 5 amps, whichever is greater				**Q**			**Q**	
A change in amperage of ± 10% or ± 10 amps, whichever is greater		**Q**	**Q**					
A change of focus current amperage of ± 5% or ± 0.1 amp, whichever is greater	**Q**							
A change of beam current amperage of ± 5% or ± 1mA, whichever is greater	**Q**							
A change of high voltage of ± 1% or ± 100 volts, whichever is greater	**Q**							
A change of arc voltage of ± 5% or ± 0.5 volts, whichever is greater				**Q**			**Q**	
A change of ± 10% wire feed speed				**Q**			**Q**	
A change in the number of electrodes in the same weld pool		**Q**	**Q**	**Q**			**Q**	
A change from the conventional welding to keyhole welding, or vice versa, or the inclusion of both techniques unless each has been individually qualified	**Q**			**Q**	**Q**		**Q**	
A change exceeding ±5% in gun-to workpiece distance, or axis of beam angle related to work	**Q**							
A change exceeding ±20% in oscillation length or width from that qualified, or the addition of a cosmetic wash pass	**Q**							
A change exceeding ±20% in the oscillation variables for mechanized or automatic welding		**Q**	**Q**	**Q**			**Q**	
A change exceeding ±10% in travel speed for mechanized or automatic welding		**Q**	**Q**	**Q**			**Q**	
A change from single-sided welds to double-sided or vice versa	**Q**				**Q**			

(Continued)

Table 5.2 (Continued)
Procedure Qualification Variables

	EBW	FCAW	GMAW	GTAW	LBW	OFW	PAW	SMAW
A change of more than 10% in the average beam power at the output coupler					**Q**			

Legend:

Fusion Welding Processes:

OFW—Oxyfuel welding
SMAW—Shielded metal arc welding
SAW—Submerged arc welding
GTAW—Gas tungsten arc welding
GMAW—Gas metal arc welding
FCAW—Flux cored arc welding
PAW—Plasma arc welding
EBW—Electron beam welding
LBW—Laser beam welding

Qualification Variables:

Q—Qualification variable for all applications
C—Qualification variable for weld cladding applications
H—Qualification variable for hardfacing applications

[a] See AWS B2.1/B2.1M-BMG—*Base Metal Grouping for Welding Procedure and Performance Qualification,* available from American Welding Society as a free download.

Table 5.3
PQR Test Requirements

Test	Groove Weld	Fillet Weld	Weld Cladding
Visual Inspection per Clause 7	Yes	Yes	Yes
Tension Test	(Note a)	(Note a)	
Metallographic Examination	(Note a)	Yes[d]	
Bend Test	Yes[c]	Yes[d]	
Fracture Toughness Test	(Note a)		
Penetrant Testing	(Note a)	Yes	Yes
Magnetic Particle Examination	Yes	(Note a)	(Note a)
Radiographic Testing	Yes for Class A welds, otherwise, see Note a.	(Note a)	(Note a)
Chemical Analysis	(Note a)		(Note a)

[a] When specified in the engineering documents or by the Engineering Authority.
[b] Minimum values shall be determined by the Engineering Authority.
[c] The use of a metallographic examination in lieu of bend testing shall be permitted only if the material is such that the specimen cannot be bent within dimensional limitation in AWS B4.0, *Standard Practice for Examination of Welds,* or Annex B.
[d] Bend testing is optional to metallographic examination for fillet weld.

5.3 Performance Qualification—General Requirements

5.3.1 Welder, Welding Operator, and Tack Welder Functional Descriptions. The definitions and functional descriptions for welder, welding operator, and tack welder are as defined in AWS A3.0.

5.3.2 Vision Test. Welders, tack welders, and welding operators shall be administered a vision acuity test at minimum once every two years. Welders and welding operators shall be administered a color perception test at minimum once

every two years, when applicable. All vision tests shall be administered by appropriately trained personnel designated by the fabricator or by qualified medical personnel. The test administrator is responsible for determining appropriate test parameters except for those specified herein. The quality organization management of the fabricator shall be responsible for determining the need for the color perception testing.

5.3.2.1 Corrected or uncorrected vision may be used to pass the test requirement. If corrected vision is used to pass the eye exam, then that fact shall be recorded on the test report. The near vision acuity shall be 20/30 or better. The test may use either Snellen, or a tumbling E chart, (or any other world language, letter, character, or symbol as deemed appropriate by the personnel administrating the test).

5.3.2.2 The test shall be an individual eye or both eyes used together to achieve eye test requirements.

5.3.2.3 The welder, tack welder, and welding operator shall successfully achieve the near vision acuity. If necessary for the welder's or welding operator's daily function, the fabricator may require color perception testing. When required, the color perception test shall be successfully achieved. The personnel administrating the test shall use any test method deemed appropriate.

5.3.3 Qualification Requirements. Qualifications, certifications, requalifications, and recertifications given under this specification do not transfer from one fabricator to another. To achieve qualified status, welders, welding operators, and tack welders shall demonstrate their skill by the following:

(1) Welders and welding operators shall produce acceptable test welds per the requirements of 5.4.8 using a qualified WPS per 5.2.1, except welder or welding operator qualification may be performed concurrently with procedure qualification as noted in 5.2.2.

(2) Tack welders shall produce acceptable test welds per 5.4.9.

5.3.3.1 Welder Qualification Variables. The qualification variables for performance qualification are as follows:

(1) welding process (see 5.4.1)

(2) base metal composition group (see 5.4.2)

(3) welding position (see 5.4.4)

(4) base metal form, sheet or tube (see 5.4.5)

(5) type of weld, groove or fillet

(6) other welding conditions (see 5.4.6)

NOTE: Filler metal alloy type used for test welds shall be the same as those used in production welding of the base metal.

5.3.3.2 Welding Operator Qualification Variables. The qualification variables for welding operators are as follows.

(1) welding process (see 5.4.1)

(2) base metal composition group (see 5.4.2)

(3) base metal thickness (see 5.4.3)

5.3.3.3 Manual Tack Welder Qualification Variables. The qualification variables for manual tack welders are as follows:

(1) welding process (see 5.4.1)

(2) base metal composition group (see 5.4.2)

(3) addition of filler material per Table 5.6

5.3.4 Qualification/Certification Validity

5.3.4.1 Initial Validity. Successful completion of welder, tack welder, and welding operator qualification tests shall be valid justification for issuance of certification for a period of two years from the date qualification test results are issued.

5.3.4.2 Extended Validity. The qualification time limits of 5.3.4.1 may be extended indefinitely provided an auditable record is maintained from the date of the initial qualification test verifying that the welder/tack welder/welding operator has not exceeded a six month period of inactivity in the process qualified.

5.3.4.3 Disqualification. Disqualification and revocation of welder certification shall result under any one or more of the following conditions:

(1) A welder, tack welder, or welding operator has not performed the qualification tests successfully within the previous two years and an auditable record has not been maintained, as required in 5.3.4.2.

(2) The welder, tack welder, or welding operator has failed the vision requirements or has not passed the required exam within the previous two years.

(3) There is a specific reason to question the ability of a welder, tack welder, or welding operator to meet the requirements for qualification.

5.3.4.4 Reinstatement. The individual disqualified may be retested for the qualification/certification sought. Reinstatement of certification shall require the individual to demonstrate ability and skills to the same or the current qualification test. The final authority for granting of certification or reinstatement of certification and retest frequency, training requirements, and overall evaluation of the individual's qualification in accord with this document rests with the fabricator.

5.3.5 Identification. The fabricator shall assign a unique number or other identification to each welder, tack welder, or welding operator upon certification.

5.3.6 Test Records. The fabricator shall complete a test record containing the qualification variables listed in paragraph 5.3.3.1, 5.3.3.2, or 5.3.3.3, detailing the limits of the welder, tack welder, or welding operator qualification. In addition, other conditions and restrictions, such as corrective lenses, shall be listed on the test record form. These records shall be retained for the period of time specified in the contract or, if no retention time is specified, the period of record retention shall be for the duration of the qualification. (See Annex G for examples of forms.)

5.4 Performance Qualification—Detailed Requirements

5.4.1 Welding Process. For welders, tack welders, and welding operators, a test weld made with a given welding process of Table 5.2 qualifies only that welding process. This qualification clause only applies to welding processes included in Table 5.2.

5.4.2 Base Metals. For welders, tack welder, and welding operators, a test weld made in a base metal included in one of the base metal groups of Table 5.4 qualifies only that base metal group, except as modified in 5.4.2.1.

5.4.2.1 Group Qualification. Qualification in a base metal group with a "B" designator also qualifies base metals with the same Roman numeral designator and an "A" designator. For example, a welder, tack welder, or welding operator qualified using Base Metal Group IIIB material for the test sample also qualifies for Base Metal Group IIIA.

5.4.2.2 Dissimilar Materials Welds. Welders, tack welders, and welding operators may also weld dissimilar alloy joints provided that they are qualified to weld each base metal alloy group represented in the joint.

5.4.3 Base Metal Thickness. The qualification limits, with regard to base metal thickness (sheet thickness or tube wall thickness), are given below for welders, tack welders, and welding operators. These limits apply to both groove welds and fillet welds.

5.4.3.1 Qualified Thickness Range and Tube Diameter

(1) A test weld with a base metal thickness of t shall qualify welds with a thickness range of 0.67t to 4t, except that when the test weld thickness is equal to or greater than 1 in [25 mm], the qualification range is 0.67t to unlimited. Two test welds shall qualify welds with all intermediate thicknesses.

(2) Qualification for sheet or tube fillet welds in material 0.063 in [1.6 mm] thickness (sheet or tube wall) or less requires a fillet weld test. A groove weld test cannot be used to qualify fillet welds in this thickness range.

NOTE: Tube fillet weld qualifications are based on tube thickness only, not mating sheet thickness.

(3) Qualification for tube welding on tubes less than 1 in [25 mm] outside diameter (OD) requires qualification of a tube weld. The tube weld qualification applies for any tube size equal to or greater than the OD of the tested tube weld.

NOTE: Qualification for tube welding on tube 1 in [25 mm] or greater may be accomplished using sheet.

5.4.4 Welding Position

5.4.4.1 Welders and Tack Welders. The welding positions qualified by a given test weld position, to be found at the left of Table 5.5, are denoted by an "X" in the table. The welding position designations are identified and illustrated in Figures 5.1, 5.2, 5.3, and 5.4.

5.4.4.2 Welding Operators. A test weld made in any position qualifies for all welding positions.

5.4.5 Base Metal Form and Weld Type

5.4.5.1 Welders and Tack Welders. The base metal forms and weld types qualified by a given test weld, to be found at the left of Table 5.5, are denoted by an "X" in the table. Operators qualified to perform groove welds are also qualified to perform plug and slot welding in the qualified position.

5.4.5.2 Welding Operators A test weld of any base metal form of any weld type shall qualify for all base metal forms and all weld types.

5.4.6 Other Welding Conditions. In addition to the welding process, base metal composition, base metal thickness, welding position, base metal form, and type of weld, other welding conditions that require a correlation between the test weld and the production welds are given in Table 5.6.

5.4.6.1 Welders and Tack Welders. The welding conditions qualified by the given test weld conditions, to be found at the left of Table 5.6, are denoted by an "X" in the table.

5.4.6.2 Welding Operators. The welding condition restrictions of Table 5.6 do not apply to the qualification of welding operators.

5.4.7 Test Welds. One test weld shall be required for each combination of welding conditions, as given in 5.3.3.1, 5.3.3.2, and 5.3.3.3, being qualified. Test welds shall be made in accordance with a WPS.

5.4.7.1 Groove Test Weld in Sheet. The test weld is a butt joint in sheet as described in Figure 5.5.

5.4.7.2 Fillet Test Weld in Sheet. The test weld is a T-joint in sheet as described in Figure 5.6.

5.4.7.3 Groove Test Weld in Tube. The test weld is a butt joint in tube as described in Figure 5.7.

5.4.7.4 Fillet Test Weld in Tube. The test weld is a tube to sheet joint as described in Figure 5.8.

5.4.7.5 Special Applications. When none of the test welds described above are applicable to a given production weld, a special welder, tack welder, or welding operator qualification limited to the specific application may be achieved with a test weld consisting of the given production weld or a test weld representative of the given production weld. The qualification is limited to the welding conditions of the test weld with regard to welding process, base metal composition, base metal thickness, welding position, base metal form, type of weld, and the other welding conditions of 5.4.6. The required inspection, examination, and acceptance criteria shall be consistent with 5.4.8 or with production part criteria.

5.4.8 Inspection and Examination Requirements

5.4.8.1 Inspection. Test welds shall be accepted or rejected in accordance with the criteria for Class A welds in Table 7.1, except a 0.5 in [13 mm] discard may be taken at the ends of groove and fillet weld coupons in sheet or plate. Inspection methods shall be performed as follows:

(1) External weld quality shall be evaluated in the as-welded condition using visual inspection.

(2) Internal weld quality shall be evaluated using radiographic testing methods for groove welds and metallographic examination for fillet welds.

5.4.8.2 Metallographic Examination. Metallographic examination using magnification of 5X–100X shall be used in place of radiographic examination for fillet welds. Blanks shall be removed in accordance with Figure 5.9 and 5.10 for fillet welds in sheet or tube. The four sections "M" to be evaluated (8 surfaces) must be separated by blanks. If the four sections "M" to be removed cannot be separated by blanks, additional test weldments shall be used to create the required number of sections "M" to be evaluated. Acceptance criteria for Class A welds and the following apply:

(1) **Base metal thickness greater than 0.063 in [1.6 mm]**. The fillet welds shall exhibit complete joint fusion (root fusion) on the eight surfaces of specimens marked "M", see Figure 5.11A.

(2) **Base metal thickness less than or equal to 0.063 in [1.6 mm].** The fillet welds may be allowed lack of root fusion not to exceed 0.1 times the fillet weld leg length, see Figure 5.11B.

(3) **Base metal thickness less than or equal to 0.063 in [1.6 mm].** Fillet welds in sheet or tube that exhibit weld metal at a sheet or tube surface opposite the weld bead and extending more than T beyond the sheet or tube surface at any cross section shall be cause for rejection, see Figures 5.11C and 5.11D.

(4) **Base metal thickness greater than 0.063 in [1.6 mm].** Fillet welds in sheet or tube that exhibit any sign of fusion at any sheet or tube surface opposite the weld bead shall be cause for rejection, see Figures 5.11C and 5.11D.

5.4.8.3 Bend Testing. Bend testing, in accordance with AWS B4.0 or Annex B, may be substituted for radiograph examination of groove welds and metallographic examination of fillet welds. If used, bend test acceptance criteria shall be as follows:

(1) **Bend Testing of Groove Welds.** Bend specimens from groove welds shall have no open discontinuity exceeding T or 1/8 in [3.2 mm] whichever is the lesser, measured in any direction on the convex surface of the specimen after bending. Cracks occurring on the corners of the specimen during bending shall not be rejected, unless there is evidence that they result from slag inclusions or other discontinuities.

(2) **Bend Testing of Fillet Welds.** Bend specimens for fillet weld bend-break tests shall be bent with the weld root in tension until the specimen either fractures or until it is bent flat upon itself. The specimen shall be accepted if:

(a) The specimen does not fracture; or

(b) If the fillet fractures, the fractured surface shall exhibit no cracks or incomplete root fusion and no inclusion or porosity in the fracture surface exceeding 3/32 in [2.4 mm] in its greatest dimension; or

(c) The sum of the greatest dimension of all inclusions and porosity in the specimen length does not exceed 3/8 in [9.5 mm].

5.4.8.4 Referee Interpretation. Test welds with NDE indications that are not clearly interpreted as rejectable may, at the sole discretion of the Engineering Authority, be subjected to supplementary testing consisting of metallographic examination, bend testing, or both, at the location of the indication, regardless of material group. Test methods and acceptance criteria shall be at the discretion of the Engineering Authority, and should be in concert with the metallographic examination requirements of this specification and the bend test methods of AWS B4.0. When no evidence of a defective weld is discovered in these supplementary tests, the test weld, all test results, and all inspection results, including radiographic film, should be considered acceptable by the Engineering Authority.

5.4.9 Tack Welding. Welders qualified in accordance with the welder performance qualification requirements of this specification are also qualified to tack weld within the limits of 5.3.3.3. Tack welder performance qualification for tack welding operations may be accomplished by performing tack welding on a production part or by producing a test coupon using a WPS. The tack welds shall be visually examined as welded, requiring a nominal 7X to 10X magnification for cracks, inclusions, and surface contamination to the Class A visual acceptance criteria. Once this initial tack welding performance qualification is complete and documented, subsequent production tack welds need only be examined to the production welding requirements.

Table 5.4
Base Metal Groups for Qualification of Welders, Tack Welders, and Welding Operators[a]

Group	Materials
IA	Carbon and Alloy Steels: • Wrought Carbon Steel: (bar, sheet, plate, and shapes): A36, A53, A106, A131, A139, A284, A441, A515, A516, A570, A572, A588, and the AISI carbon steels with a nominal carbon of 0.40 weight percent or less (1005–1040) • Cast Carbon Steels: A216, A352, A389, A487 • Cast Low Alloy Steels: A217, A389, A 487 • Low Alloy Structural Steel[b]: A514, A517, A537, A633[c] • High Strength Boiler Plate and Forgings[a]: A302, A508, A533 • Ultra High Strength Steels: 18 Ni Maraging steels, 9 Ni-4 Co steels
IB	Heat Treatable Alloy Steels: • UNS G41300[c], G41350, G41400, G43400, G86300, K22925, K44220, H11
IIA	Stainless Steels: • UNS S20100, S20200, S21900, S30100, S30200, S30300, S30400, S30800, S30900, S31000, S31600 • UNS N08330, S31700,S32100, S34700, S34800, S63198, S631989, S21900 • UNS S40500, S40900, S42900, S43000, S43400, S43600, S43035, S44100, S44200, S44600 406 • UNS S40300, S41000, S41400, S41600, S42000, S42200, S43100, S44002, S44003, S44004
IIB	Precipitation Hardenable Stainless Steels: • UNS S13800, S15500, S15700, S17400, S17700[c], S35000, S35500, S45000, S45500, S66286
IIIA	Nickel and Nickel-Based Alloys: • UNS N02200, N02201 • UNS N04400 • UNS N06002, N06007, N06455, N06600, N06625[c], N06975 • UNS N08020,N08320, N08800, N08810, N08825 • UNS N10001, N10002, N10003, N10276, N10665
IIIB	Precipitation Hardening Nickel and Nickel-Based Alloys: • UNS N05500, N06601, N07041, N07718[c], N07750, N09706, N09901, N19903, N19907, N19909 • Rene® 77, 80 • Udimet® 700
IV	Non Heat Treatable Aluminum Alloys: • UNS A91060, A91100, A93003, A93004, A95052, A95083, A95086[c], A95154, A95254, A95454, A95456, A95652 Heat Treatable Aluminum Alloys: • UNS A03550, A03560, A03570, A92014, A92219, A96061[c], A96063
V	Magnesium Alloys: • UNS M10100, M11311[c], M11610, M11800, M11910, M11920, M12330, M13210, M13310, M13312 • UNS M13320, M14141, M16620, M18220
VI	Titanium Alloys: • UNS R50250, R50400, R50550 • UNS R54520, R54620, R54810, R56210, R56260, R56320, R56400[c], R56620, R58640 • Ti-6Al-2Sn-3Zr-2Cr-2Mo • Ti-15V-3Cr-3Mo-3Sn
VII	Cobalt-Based Alloys: • UNS R30006, R30106, R30021, R30023, R30027, R30030, R30031 • UNS R30188[c], R30605, R30816
VIII	Alloys that do not conform to Groups I–VII:[d] • Refractory alloys (Cb, Mo,W) • Reactive alloys (Zr) • Magnet alloys • Copper alloys

[a] These are sample alloys. Whenever alloy trade names are suggested those alloy trade names are the property of their owners. Where trade mark names are used, the trademark will be identified by a trademark symbol.
[b] These materials shall be considered as a separate subgroup. Qualification with an alloy identified with this symbol will also qualify for welding materials in the basic group not identified by the symbol.
[c] Recommended alloy for qualification of this alloy group.
[d] Each alloy in this group requires separate qualification.

Table 5.5
Welding Position and Base Metal Form Qualified by Test Weld for Qualification of Welders, Tack Welders, and Welding Operators[a]

Test Weld			Qualified Positions[b]															
			Sheet								Tube							
			Groove				Fillet[c]				Groove[d]				Fillet[c, d]			
Form	Weld type	Position	F	H	V	O	F	H	V	O	F	H	V	O	F	H	V	O
Sheet	Groove	1G	X				X	X			X				X			
		2G	X	X			X	X			X	X			X			
		3G	X		X		X	X	X		X				X			
		4G	X			X	X	X		X	X				X			
Sheet	Fillet	1F					X								X			
		2F					X	X							X	X		
		3F					X	X	X						X			
		4F					X	X		X					X	X	X	
Tube	Groove	1G	X				X	X			X				X	X		
		2G	X	X			X	X			X	X			X	X		
		5G	X		X	X	X		X	X	X		X		X		X	X
		6G	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tube	Fillet	1F					X								X			
		2F					X	X							X	X		
		4F					X	X		X					X	X	X	
		5F					X	X	X	X					X	X	X	X

Note: In the previous edition of AWS D17.1/D17.1M:2010 the qualified positions were shown as 1G, 2G, 3G, and 4G rather than F, H, V, and O, respectively.

[a] Use of heat sinks is optional.

[b] Qualified positions for production welding are as defined in AWS A3.0. F = Flat, H = Horizontal, V = Vertical, O = Overhead.

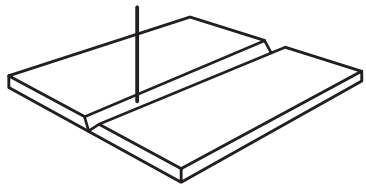
[c] Qualification for sheet or tube fillet welds in material 0.063 in [1.6 mm] in thickness (sheet of tube wall) or less requires a fillet weld test. A groove weld test cannot be used to qualify fillet welds 0.063 in [1.6 mm] or less in material thickness.

[d] A sheet test weld qualifies for tube welds 1 in [25 mm] in O.D. or greater.

Table 5.6
Other Welding Conditions Qualified by Test for Qualification of Welders and Tack Welders

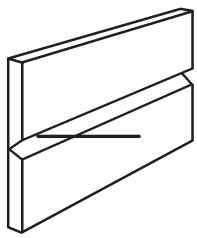
	Qualified									
	Backing Material		Groove Weld				Current Type[a]		Filler Metal	
Test Weld	With	Without	Single	Double	Complete Penetration	Partial Penetration	AC	DC	With	Without
With Backing Material	X									
Without Backing Material	X	X								
Single Welded Groove Weld			X	X						
Double Welded Groove Weld				X						
Complete Penetration Weld					X	X				
Partial Penetration Weld						X				
AC Welding							X			
DC Welding								X		
Tack Weld with Filler Metal									X	X
Tack Weld without Filler Metal										X

[a] When Applicable



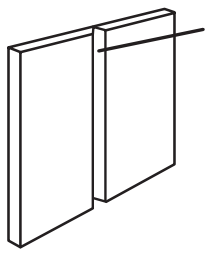
1G

Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.



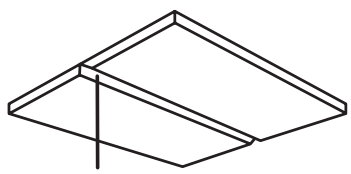
2G

Horizontal position. The position of welding in which the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane.



3G

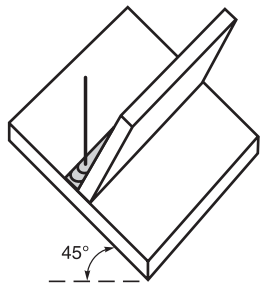
Vertical position. The position of welding in which the axis of the weld is approximately vertical.



4G

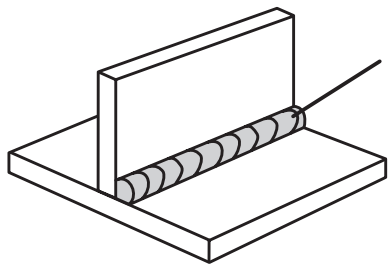
Overhead position. The position in which welding is performed from the underside of the joint.

Figure 5.1—Groove Weld in Sheet: Positions 1G, 2G, 3G, and 4G



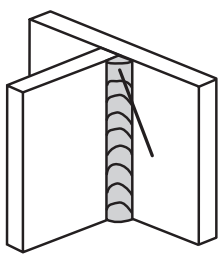
1F

Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.



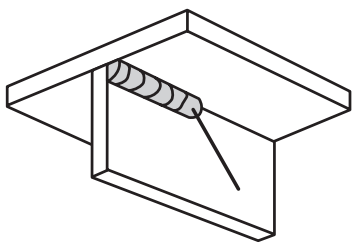
2F

Horizontal position. The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.



3F

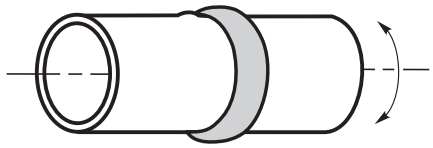
Vertical position. The position of welding in which the axis of the weld is approximately vertical.



4F

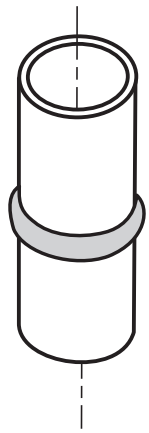
Overhead position. The position in which welding is performed from the underside of the joint.

Figure 5.2—Fillet Weld in Sheet: Positions 1F, 2F, 3F, and 4F



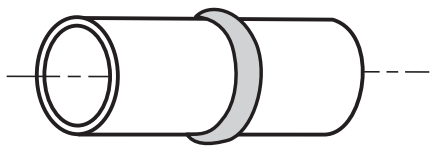
1G

Horizontal rolled position. The position of a pipe joint in which the axis of the pipe is approximately horizontal, and welding is performed in the flat position by rotating the pipe.



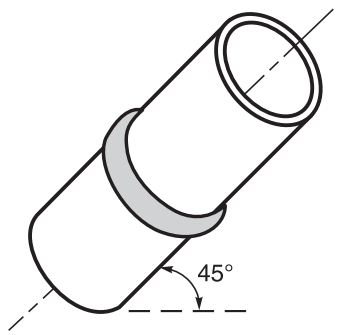
2G

Vertical position. The position of a pipe joint in which welding is performed in the horizontal position and the pipe is not rotated during welding.



5G

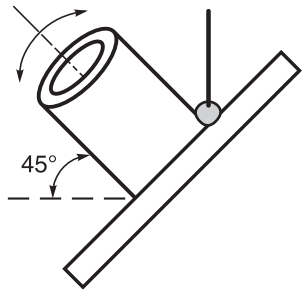
Horizontal fixed position. The position of a pipe joint in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.



6G

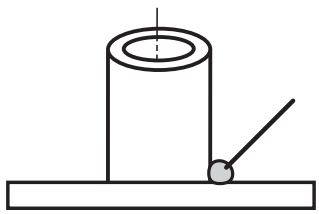
Inclined position. The position of a pipe joint in which the axis of the pipe is approximately at an angle of 45 degrees to the horizontal and the pipe is not rotated during welding.

Figure 5.3—Groove Weld in Tube: Positions 1G, 2G, 5G, and 6G



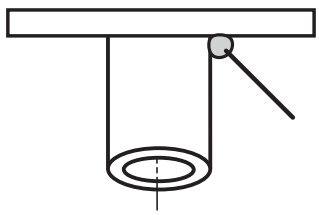
1F

Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal and the pipe is rotated during welding.



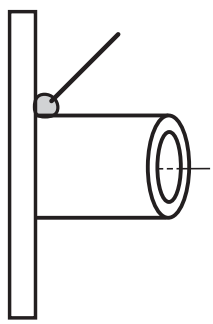
2F

Horizontal position. The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface and the pipe is not rotated during welding.



4F

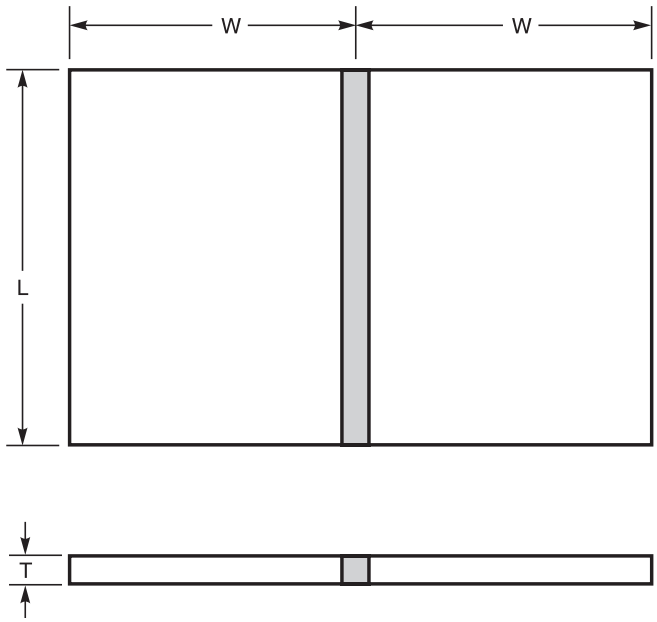
Overhead position. The position in which welding is performed from the underside of the joint and the pipe is not rotated during welding.



5F

Multiple Position. The position in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.

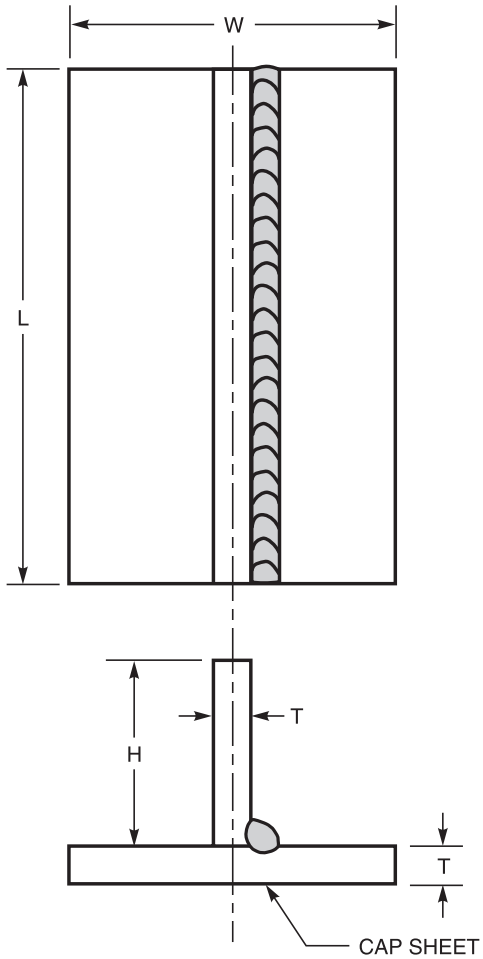
Figure 5.4—Fillet Weld in Tube: Positions 1F, 2F, 4F, and 5F



Base Metal Thickness (in [mm])		Minimum Dimensions (in [mm])
T	**W**[a]	**L**
≤ 0.063 [1.6]	2 [50]	5 [125]
> 0.063 [1.6]	3 [75]	8 [200]

[a] Suggested Dimension

Figure 5.5—Groove Test Weld in Sheet

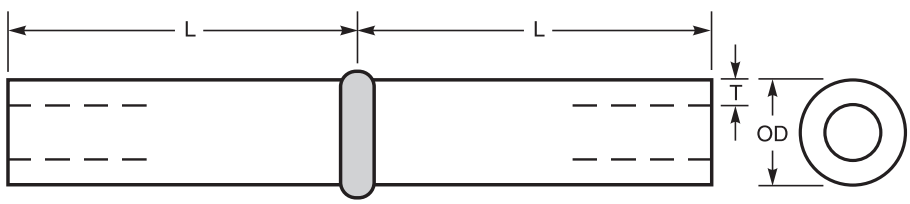


Base Metal Thickness (in [mm])	Minimum Dimensions (in [mm])		
T	**W**[a]	**L**	**H**
≤ 0.063 [1.6]	4 [100]	5 [125]	2 [50]
> 0.063 [1.6]	6 [150]	8 [200]	3 [75]

[a] Suggested dimension.

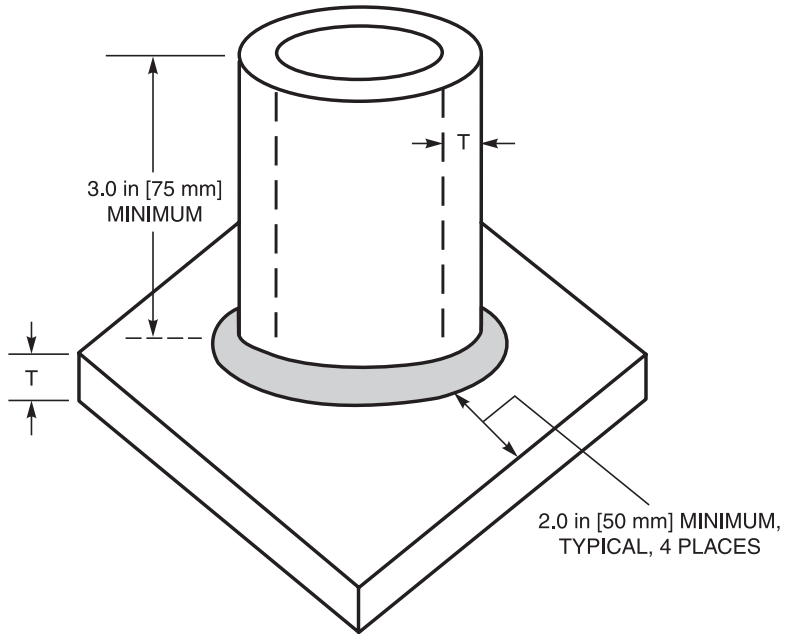
Note: Where the members differ in thickness more than 10% of the thicker member, the cap sheet shall be the thicker member.

Figure 5.6—Fillet Test Weld in Sheet



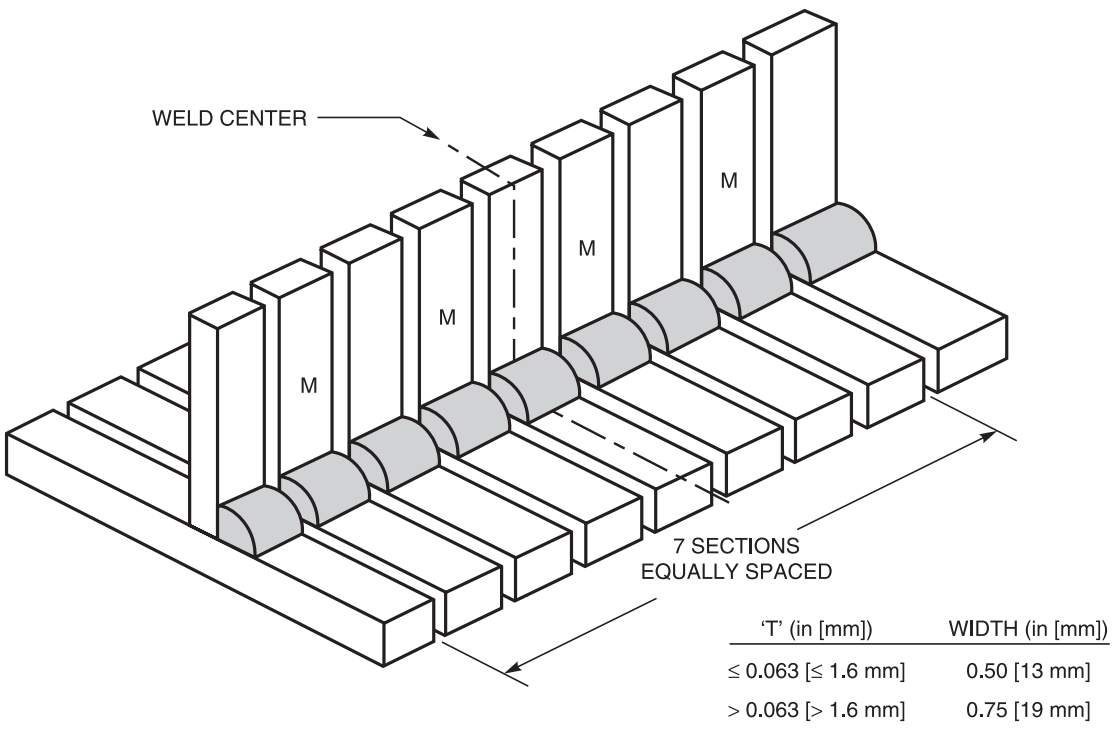
Base Metal Thickness (in [mm])	Minimum Dimensions (in [mm])
T	**L**
≤ 0.063 [1.6]	2 [50]
> 0.063 [1.6]	3 [75]

Figure 5.7—Groove Test Weld in Tube



Note: Where the members differ in thickness equal to or more than 10% of the thicker member, the sheet shall be the thicker member.

Figure 5.8—Fillet Test Weld in Tube



'T' (in [mm])	WIDTH (in [mm])
≤ 0.063 [≤ 1.6 mm]	0.50 [13 mm]
> 0.063 [> 1.6 mm]	0.75 [19 mm]

Figure 5.9—Blank Locations for Metallographic (M) Specimens in Fillet-Welded Sheet

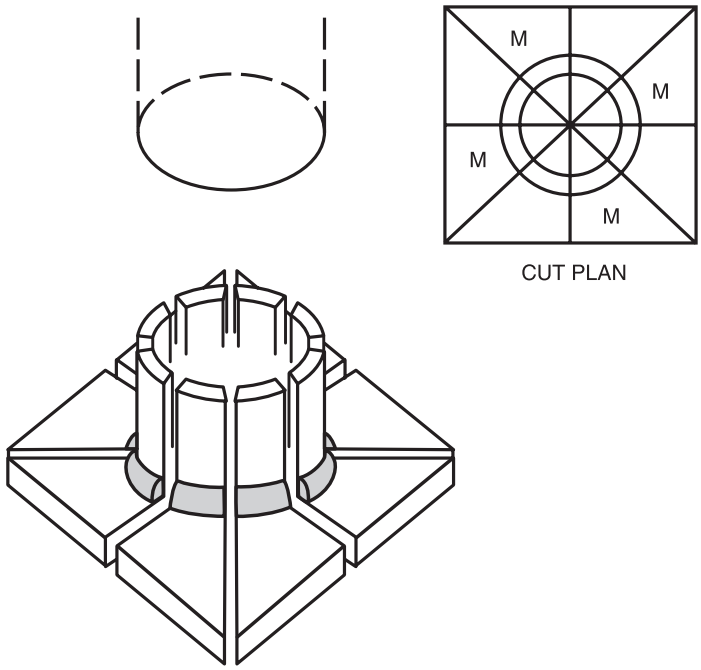
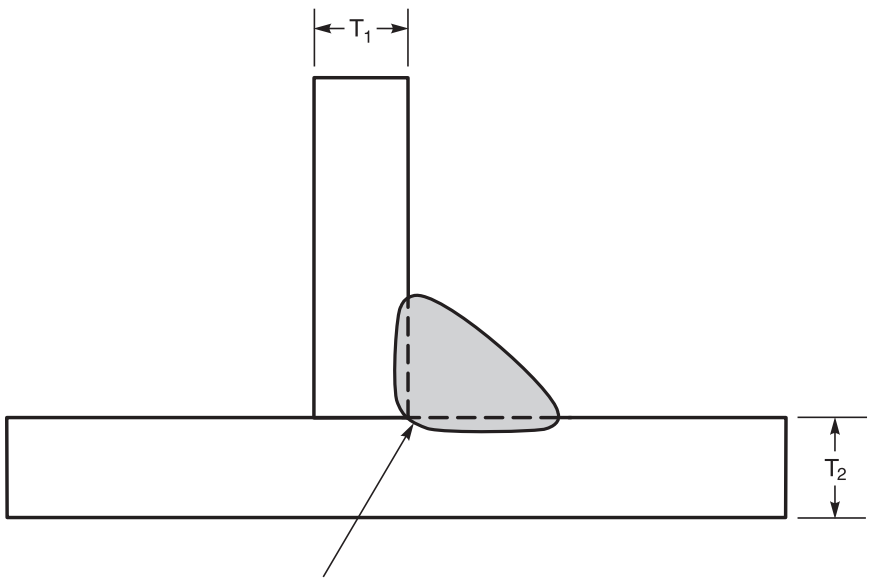
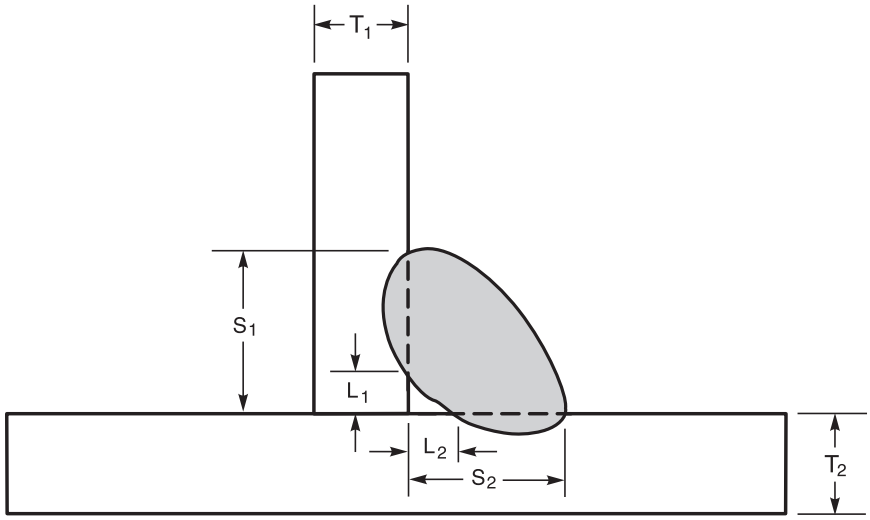


Figure 5.10—Blank Locations for Metallographic (M) Specimens in Fillet-Welded Tube



Notes:
1. When the thickness of both members (T_1 and T_2) is >0.063 in. [1.6 mm], there shall be evidence of melting and fusion of both members at the corner and weld metal penetration beyond the junction of two members.
2. When the thickness of either member (T_1 or T_2) is ≤0.063 in. [1.6 mm], requirements of Figure 5.11B shall be met.

Figure 5.11A—Complete Fusion at Root in Fillet Welds When Thickness of Both Members is Greater Than 0.063 in [1.60 mm]



Legend:
L_1 = Measured incomplete fusion at the root in vertical member
L_2 = Measured incomplete fusion at the root in horizontal member
S_1 = Measured leg size in vertical member
S_2 = Measured leg size in horizontal member

Notes:
1. When thickness (T_1 or T_2) of either member is ≤0.063 in [1.6 mm]. L_1 shall be ≤0.1 × S1 and/or L_2 shall be ≤0.1 × S2.
2. When thickness (T_1 and T_2) of both members is >0.063 in [1.6 mm], requirements of Figure 5.11A shall be met.

Figure 5.11B—Incomplete Fusion at Root in Fillet Welds When Thickness of Any Member is Less Than or Equal to 0.063 in [1.6 mm]

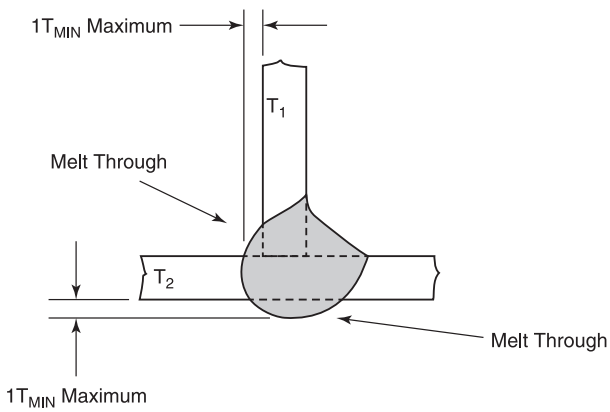
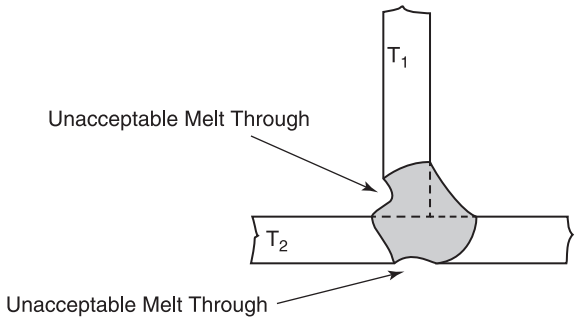


Figure 5.11C—Condition of Surfaces Opposite Lap and T-Joint Fillet Welds—Melt Through in Fillet Welds



Notes:
1. When thickness (T_1 or T_2) of any member is > 0.063 in [1.6 mm], melt through evident at any sheet or tube surface opposite the weld bead shall be cause for rejection. See Figures 5.11C and 5.11D.
2. When thickness (T_1 or T_2) of any member is ≤0.063 in [1.6 mm], melt through evident at any sheet or tube surface opposite the weld bead face shall not exceed 1T of the thinnest member (Figure 5.11C) and fusion shall not reduce the base material thickness (Figure 5.11D).

Figure 5.11D—Condition of Surfaces Opposite Lap and T-Joint Fillet Welds—Unacceptable Melt Through in Fillet Welds

6. Fabrication

6.1 Scope. This clause establishes requirements for the fabrication of weldments.

6.2 Welding Consumables

6.2.1 Identification (Bare Welding Wire and Welding Rods, Electrodes, Inserts, and Fluxes). Consumables used in welding shall be identified in accordance with an established standard or specification or by a standard specified in the procurement specification. If the identification marking is destroyed or missing, the consumable shall not be used. When specified on the engineering drawing or a contract document, traceability of the consumables shall be maintained throughout the welding process.

6.2.2 Storage and Use

6.2.2.1 Filler Metals. Welding filler materials shall be stored in a clean and dry environment. Filler metal types shall not be commingled during storage or use. Heating may be employed as necessary to prevent moisture accumulation. Low hydrogen SMAW and FCAW electrodes shall be handled and stored according to manufacturer's recommendations or according to AWS A5.1/A5.1M, A5.5/A5.5M, A5.20/A5.20M, or A5.29/A5.29M, as appropriate.

6.2.2.2 Welding Fluxes. Fluxes shall be labeled and segregated by type and/or by their particular application. To prevent moisture pickup, fluxes shall be stored in sealed containers or be kept in a suitably clean and dry environment. Clean unfused flux may be reused after reconditioning according to the manufacturer's recommendations.

6.2.3 Gases

6.2.3.1 Gas Procurement Specification. Welding and shielding gases shall be procured to the requirements of Table 6.1 or to the requirements of AWS A5.32M/A5.32. Gases may be procured to the alternate specifications in Table 6.1, with the approval of the Engineering Authority.

6.2.3.2 Shielding Gas(es). When the welding process requires the use of a shielding gas, the gases or gas mixtures designated in Table 6.2 are recommended for each of the different base materials. When parts are welded in accordance with a qualified WPS, the chemical composition, volume percentage, and flow rate of each gas shall be as specified in the qualified WPS.

Table 6.1
Gas Requirements[a]

Gas	Specification	Alternate Specification
Argon	MIL-A–18455	CGA G–11.1
Helium	BB-H–1168	CGA G–9.1
Oxygen	BB-O–925, Type I OR II	CGA G–4.3
Nitrogen	A-A–59503, Type I OR II, Class 1, Grade B	CGA G–10.1
Hydrogen	BB-H–886, Type I OR II	CGA G–5.3
Acetylene	BB-A–106, Grade B	CGA G–1.1
Carbon Dioxide	BB-C–101, Grade B	CGA G–6.2
Gas Mixtures—The purity of the gases in the mixture shall be as specified for the individual gas listed above. Composition of the gas mixture shall be as specified by the Engineering Authority.		

[a] Refer to paragraph 6.2.3.1

Table 6.2
Recommended Shielding Gases for Welding[a]

Material	Gas[b]							
	Ar	He	Ar-He	Ar-O_2[c]	Ar-H	N	CO_2	Ar-CO_2
Aluminum and Its Alloys	X	X	X					
Cobalt and Its Alloys	X	X	X		X			
Copper and Its Alloys	X	X	X					
Magnesium and Its Alloys	X	X	X					
Nickel and Its Alloys	X	X	X					
Stainless Steel Alloys	X	X	X	X		(Note d)		
Plain Carbon Steels	X	X	X	X			(Note e)	(Note e)
Low Alloy Steels	X	X	X	X				(Note e)
Titanium and Its Alloys	X	X	X					

[a] Refer to paragraph 6.2.3.2.
[b] Gas Compositions and mixtures shall comply with Table 6.1.
[c] 8 % oxygen maximum.
[d] Recommended for backing only.
[e] Only recommended on plain carbon steels or low alloy steels with a maximum of 0.25% nominal carbon.

6.3 Welding Equipment. The welding equipment shall be capable of maintaining weld quality and consistency.

6.3.1 Calibration

6.3.1.1 Meters, Gauges, and Dials. Meters, gauges, and dials installed on automatic, mechanized, or robotic welding apparatus shall be calibrated in accordance with an established procedure.

6.3.1.2 Gas Flow Meters and Pressure Gauges. Gas flow meters and pressure gauges do not require calibration.

6.3.1.3 Calibration Procedures. The fabricator shall establish and document applicable calibration procedures.

6.3.1.4 Calibration Period. Required calibrations shall be performed at an interval of two (2) years or less. Required calibrations shall also be performed when meters, gauges, and dials have been affected by repairs made to automatic, mechanized, or robotic welding apparatus.

6.4 Weld Settings. When parts are welded in accordance with a qualified WPS, weld settings shall be within the limits specified in the WPS.

6.4.1 Reproducibility Tests for Qualified Machine Welding Settings

6.4.1.1 Applicability of Requirements. These requirements are applicable to automatic, mechanized, and robotic equipment only. The reproducibility test shall be performed according to 6.4.1.2 when either of the following is encountered:

(1) The equipment fails to produce acceptable weld quality in accordance with the settings of a qualified WPS.

(2) A major component of the equipment is either repaired or replaced (as determined by the fabricator).

6.4.1.2 Test Requirements. The reproducibility test shall be performed according to a written procedure. The written procedure shall establish welding parameters, test specimen configuration, and acceptance criteria for the welded test specimen(s).

6.5 Preweld Cleaning and Other Preparation

6.5.1 Surface Cleaning. All surfaces to be welded and surfaces that may affect quality of the resulting weld (e.g., welding filler materials and fixtures) shall be free from slag, surface oxides, scale, protective finishes, oils, grease, dirt, or any other contaminants. Chemical methods (e.g., alkaline cleaning, solvent wipe, or etching) or mechanical methods (e.g., wire brushing, scraping, abrasive blasting, or machining) shall be used before welding, as needed, to ensure compliance to these requirements.

CAUTION: Chlorinated solvents or methyl alcohol shall not be used when cleaning titanium or titanium alloys.

CAUTION: Austenitic stainless steel wire brushes or carbon steel wire brushes may be used on carbon or low alloy steels. Only austenitic stainless steel wire brushes shall be used on all other materials being welded. Once an individual wire brush is used on a certain material group, it shall be suitably identified with the respective material group. Brushes identified as carbon or low alloys steels, titanium, magnesium, or aluminum shall only be used on the respective material group identified on the brush. Brushes identified as nickel, SS, or cobalt may be used on any material from the nickel, SS, or cobalt alloy groups. Brushes used on the VIII group shall be identified by alloy type.

6.5.2 Contamination of Cleaned Surfaces. Previously cleaned surfaces shall be protected from contamination. If contamination does occur, the surfaces shall be cleaned again by one of the methods specified in 6.5.1 before welding.

6.6 Preweld Joint Preparation and Fitup

6.6.1 Joint Preparation. The edge of each joint member shall be prepared as specified by the weld symbols on the engineering drawing.

NOTE: Annex A provides guidelines for joint preparation.

6.6.2 Fitup Gap. Unless otherwise specified on the Engineering drawing or WPS, fitup tolerances shall be in accordance with Annex A.

6.6.3 Flange Joint Fitup. Flange joint fitup shall be in accordance with the weld symbols on the engineering drawing.

NOTE: Annex A provides guidelines for the flange joint fitup.

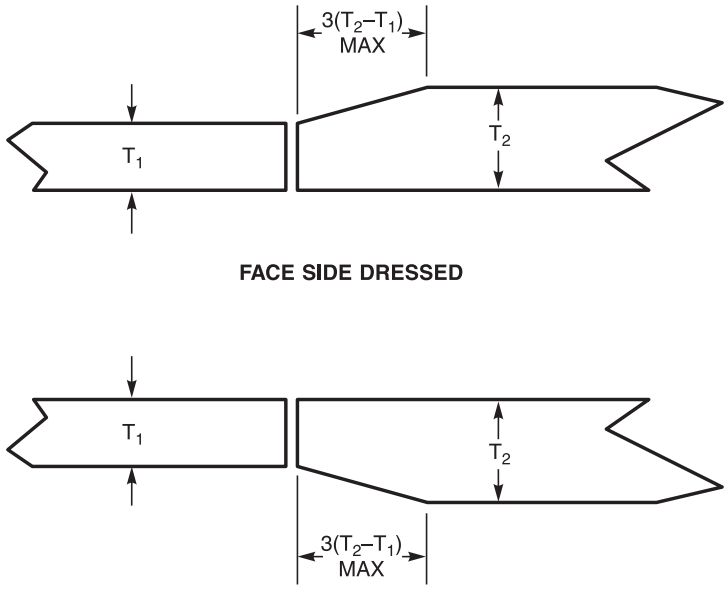
6.6.4 Joint Members of Unequal Thickness

6.6.4.1 Joint Member Preparation. Joint members shall be prepared as shown in Figure 6.1 when the following conditions exist:

(1) a full penetration weld is specified on the engineering drawing

(2) both joint members exceed 0.125 in [3.2 mm] in thickness

(3) the thickness ratio between joint members meets or exceeds: 1.5:1



Note: Refer to 6.6.4.1.

Figure 6.1—Joint Preparation in Joint Members of Unequal Thickness

6.7 Preheating and Interpass Temperature Control. Preheating and interpass temperature shall be established for materials susceptible to cracking during or after welding. Temperatures which are found to reduce the tendency to form cracks shall be included in the WPSs and employed when welding production hardware.

NOTE: Table 6.3 provides recommended preheat and interpass temperatures for some materials.

Table 6.3
Preheat and Interpass Temperatures[a]

Base Metal Being Welded	Recommended Preheat and/or Interpass Temperature
Carbon and Alloy steel with carbon equivalent 0.35% or greater[b]	600°F Maximum[b,c] [315°C Maximum]
Magnesium alloys in condition F	450°F to 500°F [232°C to 260°C]
Magnesium alloys in condition T	250°F to 300°F [121°C to 149°C]

[a] Refer to 6.7
[b] The method provided in AWS D1.1/D1.1M may be used to determine carbon equivalent, preheat temperature, and interpass temperature.
[c] This is a maximum temperature. Depending upon part configuration and weld environment, the user should establish a temperature equal to or less than this temperature that is suitable for use in production welding.

6.8 Tack Welds. Filler material used for tack welds shall be the same as that used for subsequent welding unless otherwise specified on the engineering drawing or listed in the qualified and Engineering Authority-approved WPS. Tack welds shall be consumed during subsequent welding unless removed in other processing. The requirements of 6.6 and 6.7 will be considered during the tack welding operations.

6.9 Weld Start and Run-Off Tabs. Weld start and run-off tabs, when used, shall be composed of the same alloy as the joint members. They shall be welded with the same filler material as that filler material specified on the engineering drawing or the qualified and Engineering Authority-approved WPS.

6.10 Weld Shielding for GTAW, GMAW, and PAW. The weld and the heat-affected zones (including deposited weld metal behind the weld pool in reactive materials, such as titanium and its alloys) shall be protected from oxidation during welding. The shielding method shall be included in the WPS and shall be used during the welding of the reactive materials, such as titanium and its alloys.

6.11 Tungsten Electrodes. Tungsten electrodes, when required, shall be in accordance with AWS A5.12M/A5.12 (ISO 6848 MOD), *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting*.

6.12 Filler Materials. Any welding process requiring filler material shall only be performed using the filler material specified on the WPS as specified by the engineering drawing. When a filler material is not specified, welding shall not be performed until the Engineering Authority provides pertinent filler material information. This requirement is not applicable to autogenous welds (welds made without filler material). The filler material information provided in Tables 6.4, 6.5, and 6.6 is for general guideline use and shall not be used for filler metal selection without direction from the Engineering Authority.

Table 6.4
Filler Metal Guidelines for Welding Aluminum Alloys Using GMAW, GTAW, and PAW Processes[a]

Base Metal	Filler Material	Filler Material Specification
A91100	A91100 or A94043	AWS A5.10/A5.10M
A93003	A91100 or A94043	AWS A5.10/A5.10M
A92212	A92319	AMS 4191 or AWS A5.10/A5.10M
A95052	A95356 or A94043	AWS A5.10/A5.10M
A96013	A94043	AWS A5.10/A5.10M
A96061	A94043 or A95356	AWS A5.10/A5.10M

[a] Refer to F6.12 and 6.12.

Table 6.5
Filler Metal Guidelines for Welding Titanium Alloys Using GMAW, GTAW, and PAW Processes[a]

Base Metal	Filler Material	Filler Material Specification
R50250, RR	R50120	AMS 4951
R50400, R50550, R52400	R52400	AWS A5.16/A5.16M
R56320	R56320	AWS A5.16/A5.16M
R54520	R54520	AMS 4953
	R54520	AWS A5.16/A5.16M
R56400 or R56402	R56408	AMS 4956
		AWS A5.16/A5.16M

[a] Refer to F6.12 and 6.12.

Table 6.6
Filler Metal Guidelines for Welding Stainless Steels and Heat-Resistant Alloys Using GMAW, GTAW, and PAW Processes[a]

Base Metal	Filler Material	Filler Material Specification
S30403 and S31603	S30883	AWS A5.9/A5.9M
S32100 and S34700	S32180 or S34780	AWS A5.9/A5.9M
K66286	A286	AMS 5804 or AMS 5805
S21900	S21980	AWS A5.9/A5.9M
S13800	S13559	AMS 5840
S15700	S15789	AMS 5812
S15500	S15500 or S17480	AMS 5826 or AWS A5.9/A5.9M
S17400	S17480	AMS 5825 or AWS A5.9/A5.9M
S17700	S17780	AMS 5824
	S15789	AMS 5812
N06600	N06062	AWS A5.14/A5.14M
N06625	N06625	AMS 5837
	N10004	AMS 5786 or AWS A5.14/5.14M
N07718	N07718	AMS 5832
N07750[b]	N06052	AWS A5.14/A5.14M

[a] Refer to F6.12 and 6.12.
[b] Refer to Annex D for a cross-reference between alloy numbers, proprietary trade names and UNS numbers.

6.13 Interpass Cleaning. When interpass cleaning is performed, mechanical methods specified in 6.5.1 shall be used.

6.13.1 Interpass Cleaning of Titanium and Titanium Alloys. Interpass cleaning of titanium or titanium alloy parts shall only be performed following visual inspection and acceptance of the surface discoloration to the requirements of Table 7.1.

6.14 Welding and Weldments. The welding of joint members and the resulting weldment shall comply with the requirements specified in the following subclauses:

6.14.1 Weld Settings. Before starting a welding cycle, the settings on the welding equipment shall be set to those listed in the qualified WPS.

6.14.1.1 Arc Strike. The welding arc shall not be struck on any portion of the base metal away from the surfaces to be joined. When indication of an arc strike or an arc burn is present in an area other than the deposited weld metal, the weldment shall be rejected as required in Clause 7.

6.14.2 In-Process Correction. Any correction of a weld made by the welder before submitting the weldment for acceptance inspection in accordance with Clause 7 is an in-process correction. The correction shall not change the metallurgical or physical condition of the base metal. The correction shall occur before subjecting the weld to any heat treat operations. Before initiating in-process correction, surfaces to be welded shall be cleaned to remove oxide and other contaminants in accordance with 6.5.1.

6.14.2.1 Welds Made Using Filler Material. For welds made using filler material the following applies:

(1) An undercut, underfill, or crater (without crack) shall be considered as a surface depression and corrected by depositing filler material (the same as used in making the original weld) that blends into the weld and the base metal.

(2) An overlap, weld reinforcement, or other protruding indication may be removed by a metal removal method that will not degrade the material's properties. Corrections shall be performed in such a manner that the weld size and base metal thickness will remain within drawing tolerances. The corrected weld bead shall comply with Clause 6.14.3.

6.14.2.2 Mechanized, Automatic, or Autogenous Welds. In-process corrections using nonmanual or autogenous welds may be performed providing the same process and parameters are used as used in original weld. Any other process or parameters are only allowed when the engineering drawing or contract document allows such correction.

6.14.2.3 Allowed Number of In-Process Correction Attempts. One in-process correction attempt is allowed in each individual flaw location. When the in-process correction requires more than one attempt at the same flaw location, the combination of corrections shall be qualified as the original weld (with WPS and supporting PQR) or approved by the appropriate Material Review Board.

6.14.2.4 Documentation of In-Process Correction. The in-process correction history shall be documented when required by the Engineering Authority. The method and extent of documentation shall be that agreed upon by the Engineering Authority and the fabricator.

6.14.3 Removal of Weld Reinforcement. Weld reinforcement removal shall be accomplished using methods that do not reduce the thickness of the base metal. Weld reinforcement shall only be removed for one or more of the following reasons:

(1) When specified by the engineering drawing notes or weld symbol. (The removal shall not exceed limits specified on the engineering drawing or any other contractual document).

(2) When necessary to aid in the interpretation of nondestructive inspection indications. Remaining reinforcement shall be visually evident above the surface plane of the adjacent joint member and extend throughout the weld bead width. The weld toe area shall comply with the requirements of Clause 7.

(3) When fit or function of the final assembly dictate material removal. Remaining reinforcement shall be visually evident above the surface plane of the adjacent joint member and extend throughout the weld bead width. The weld toe area shall comply with the requirements of Clause 7.

6.15 Postweld Cleaning. The completed weldment shall be free of spatter, flux, scale, slag, or other foreign matter. Removal of such material during the postweld cleaning operation shall not reduce the weld bead size or base metal thickness below engineering drawing tolerances.

6.15.1 Postweld Cleaning of Welded Titanium or Titanium Alloy Parts. Postweld cleaning of welded titanium or titanium alloy parts shall only be performed after completion of a visual inspection and acceptance of the surface discoloration in accordance with Table 7.1.

6.16 Postweld Processing. Stress relieving, heat treatment, or any other postweld processing of the weldment shall be as specified on the engineering drawing or the qualified WPS.

6.17 Weld Identification Requirements

6.17.1 Interim Identification. Each welder/welding operator shall identify his work by interim marking the weldment or by marking the applicable shop planning paperwork. Alternate tracking methods may be used with approval from the Engineering Authority. The interim identification shall remain next to or with the weld through final inspection. Marking methods and materials used shall neither be detrimental to the base metal nor interfere with subsequent operations.

6.17.2 Final Identification. Each welded assembly or the documentation accompanying each welded assembly shall be marked as follows:

(1) date of welding

(2) welder's signature or individually assigned stamp or code

(3) date of weld inspection

(4) weld inspector's signature or individually assigned stamp or code

6.18 Acceptance Inspection. The completed weldment shall be submitted to the fabricator's quality assurance organization or its designee for an acceptance inspection. The acceptance inspection shall be performed in accordance with Clause 7.

6.19 Rework. Rework is any corrective action made to a weldment in the as-welded condition following acceptance inspection. The corrective action shall bring the weldment into full conformance with the engineering drawing and the requirements of this specification. Except as specified herein, every requirement of 6.14 applies for rework.

6.19.1 Allowed Number of Rework Attempts. The allowed number of rework attempts shall be as established in the WPS and supporting PQR.

6.19.2 Root Area Rework. A weld with inadequate penetration or incomplete fusion at the root may be corrected by welding from the root side. Proper preparation of the root side shall be performed to obtain sound metal prior to welding. The prepared surface shall smoothly fair into all surfaces to be fused in the rework.

6.19.3 Documentation of Rework. All operations involved in rework shall be documented using a method approved by the Engineering Authority.

6.19.4 Inspection of the Rework. The reworked weldment shall be submitted for an acceptance inspection in accordance with Clause 7.

6.20 Repair. Repair is any corrective action on a part directed by the Customer or its designee (Material Review Board). Repairs may be made to repair defects in welds.

6.20.1 Repair Instructions. The Engineering Authority or its designee shall provide detailed instructions for the repair that include but are not limited to:

(1) allowed number of weld repair attempts

(2) required documentation

(3) details for each operation (including acceptance criteria) involved in the repair

7. Inspection

7.1 Qualification of Inspection Personnel

7.1.1 Qualification of NDE Personnel. Nondestructive examination personnel shall be qualified in accordance with NAS 410 or an other NDE standard that is satisfactory to the Engineering Authority. When the contract, purchase order, or engineering drawing specifies the use of an examination method not presently incorporated in NAS 410, the fabricator shall be responsible for developing and submitting to the Engineering Authority the training program, written practice, examination, and practical demonstrations equivalent to the requirements of NAS 410 or other standards. These shall establish the capability of the personnel performing the required examination.

7.1.2 Visual Weld Inspectors. All personnel performing visual weld inspections shall be certified by one of the following:

(1) AWS QC1

(2) a certification program approved by the Engineering Authority

(3) a certification program approved by the fabricator's quality organization management, that is based on experience, training, and testing criteria cited in AWS B5.2

7.1.3 Vision Test. Visual weld inspectors shall be administered a vision acuity test at minimum once every two years. Visual weld inspectors shall be administered a color perception test at minimum once every two years, when applicable. All vision tests shall be administered by appropriately trained personnel designated by the fabricator or by qualified medical personnel. The test administrator is responsible for determining appropriate test parameters except for those specified herein. The quality organization management of the fabricator shall be responsible for determining the need for the color perception testing (e.g. inspection of titanium weldments).

7.1.3.1 Corrected or uncorrected vision may be used to pass the test requirement. If corrected vision is used to pass the exam, that fact shall be recorded in the test report. The near vision acuity shall be 20/30 or better. The test may use either Snellen, or a tumbling E chart, or any other world language, letter, or any character or symbol as deemed appropriate by the personnel administrating the test.

7.1.3.2 The test shall be an individual eye or both eyes used together to achieve eye test requirements.

7.1.3.3 The visual weld inspector shall successfully achieve the near vision acuity. If necessary for the visual weld inspector's daily function, the fabricator may require color perception testing. When required, the color perception test shall be successfully achieved. The personnel administrating the test shall use any test method deemed appropriate.

7.2 Visual Weld Inspection. All welds shall be visually inspected for conformance to drawing requirements by personnel qualified in accordance with 7.1.2.

7.3 Nondestructive Examination. NDE inspections are required to be performed using written procedures approved by an NDE Level III inspector certified in the appropriate inspection method.

7.3.1 Penetrant Testing (PT). All nonferromagnetic Class A and Class B welds shall be penetrant tested. Ferromagnetic Class A and Class B welds shall be penetrant tested when specified on the drawing or in the contract. Class C nonferromagnetic and ferromagnetic welds shall be penetrant tested when specified on the drawing or in the contract. Penetrant testing shall be conducted in accordance with ASTM E 1417 using an approved Type I penetrant system, any method, sensitivity level 2 or better, and with or without developer. Equivalent processes may be used with engineering authority approval.

7.3.2 Magnetic Particle Testing (MT). All ferromagnetic Class A and Class B welds shall be magnetic particle tested using a wet fluorescent continuous method in accordance with ASTM E1444 or equivalent, unless penetrant testing is required by the drawing or contract. Class C ferromagnetic welds shall be magnetic particle tested when specified on the drawing or in the contract.

7.3.3 Radiographic Testing (RT). All Class A groove welds shall be radiographically tested in accordance with ASTM E1742 or equivalent, unless ultrasonic testing is required by the drawing or in the contract. When radiographic testing of fillet welds or partial penetration groove welds is required, the acceptance criteria of the root shall be determined by the Engineering Authority. Class B and Class C welds shall be radiographically tested when specified on the drawing or in the contract.

7.3.4 Ultrasonic Testing (UT). Ultrasonic testing may be used in lieu of radiographic testing when specified by the drawing, in the contract, or by the Engineering Authority. Ultrasonic testing shall be in accordance with ASTM E164, or equivalent. When immersion or phased array ultrasonic testing is indicated, an approved standard shall be determined by the Engineering Authority.

7.3.5 Proof Testing (PRT). Proof testing may be used in conjunction with or in lieu of inspection methods listed in 7.3.1, 7.3.2, 7.3.3, and 7.3.4 when required by the drawing, in the contract, or when directed by the Engineering Authority (see Annex F—Commentary).

7.3.6 Other Nondestructive Tests. Nondestructive tests, procedures, techniques, equipment, or materials (e.g., Acoustic Emission, Electromagnetic or Eddy Current, Leak, Neutron Radiographic, etc.) not specifically addressed in this document may be used in conjunction with those stated on drawing or in the contract. When one or more of these inspection methods are indicated, an approved standard shall be determined by the Engineering Authority.

7.4 Acceptance Criteria

7.4.1 General. The dimension of any discontinuity shall be defined by its largest dimension. Two or more discontinuities shall be treated as one when the spacing between them is less than the dimension of the larger discontinuity. Discontinuities that will be removed in subsequent machining shall not be cause for rejection. Any weldment with unacceptable discontinuities which has gone through a subsequent manufacturing operation that affects the metallurgical characteristics (other than hydrogen embrittlement relief) or that cannot be rewelded without affecting final metallurgical or surface characteristics shall be rejected. Removal of unacceptable weld metal is allowed provided that the minimum weld size is met. Incidental removal of base metal during discontinuity removal is acceptable provided minimum thickness requirements and any other engineering requirement (e.g., surface roughness) are met. In the case of weldments with variations in cross section along the joint, the thickness (T) shall be considered to be the minimum thickness at the discontinuity.

7.4.1.1 When performing visual inspection to determine acceptance of welded product, welds shall be inspected at magnifications from 1X to 10X. Discontinuities not detectable in this range shall not be cause for rejection. When measurements are taken at magnification over 10X (see 5.4.8.2), the rounding method of ASTM E29 shall be applied to all measured values in determining conformance/acceptance/rejection to the applicable requirements and associated significant digits within the requirement.

7.4.2 Acceptable Welds. Welds shall be acceptable if they satisfy the conditions of Table 7.1. Welds not meeting these requirements shall be rejected.

7.4.2.1 Mismatch. Unless otherwise specified on the engineering drawing or in any other contractual document, the maximum mismatch between joint members after welding shall meet the requirements of Figure 7.2.

7.4.2.2 Angular Distortion or Peaking. Unless otherwise specified on the engineering drawing or in any other contractual document, the angular distortion or peaking present upon completion of welding shall be within five degrees of the angle shown on the engineering drawing.

Table 7.1
Acceptance Criteria (in [mm])

Discontinuity	Class A	Class B	Class C
Cracks	None	None	None
Overlap (Cold Lap)	None	None	None
Incomplete Fusion	None	None	None
Incomplete Penetration[a]	None	None	None
Porosity—Surface			
Individual size maximum	0.25 T or 0.030 [0.76], whichever is less	0.33 T or 0.060 [1.5], whichever is less	0.50 T or 0.090 [2.3], whichever is less
Spacing minimum	8 times the size of the larger adjacent imperfection[b]	4 times the size of the larger adjacent imperfection[b]	2 times the size of the larger adjacent imperfection[b]
Accumulated length in any 3 in [75 mm] of weld maximum	1 T or 0.12 [3.1], whichever is less	1.33 T or 0.24 [6.1], whichever is less	2 T or 0.36 [9.1], whichever is less
Porosity—Subsurface			
Individual size maximum	0.33 T or 0.060 [1.5], whichever is less	0.50 T or 0.090 [2.3], whichever is less	Not applicable
Spacing minimum	4 times the size of the larger adjacent imperfection[b]	2 times the size of the larger adjacent imperfection[b]	Not applicable
Accumulated length in any 3 in [75 mm] of weld maximum	1.33 T or 0.24 [6.1], whichever is less	2 T or 0.36 [9.1], whichever is less	Not applicable
Inclusions			
Individual size maximum	0.33 T or 0.060 [1.5], whichever is less	0.50 T or 0.090 [2.3], whichever is less	Not applicable
Spacing minimum	4 times the size of the larger adjacent imperfection[b]	2 times the size of the larger adjacent imperfection[b]	Not applicable
Accumulated length in any 3 in [75mm] of weld—maximum	1.33 T or 0.24 [6.1], whichever is less	2 T or 0.36 [9.1], whichever is less	Not applicable
Undercut			
For the full length of weld maximum depth	0.002 [0.051]	0.015 T or 0.002 [0.051], whichever is greater	0.025 T or 0.002 [0.051], whichever is greater
Individual defect, maximum depth	0.07 T or 0.030 [0.76], whichever is less	0.10 T or 0.050 [1.3], whichever is less	0.20 T or 0.070 [1.8], whichever is less
Accumulated length in any 3 in [75mm] of weld maximum	0.20 [5.1]	0.60 [15]	1.00 [25]
Face or Root Underfill (Groove Welds)			
For the full length of weld – maximum depth	0.005 [0.13]	0.015 T or 0.005 [0.13] whichever is greater	0.025 T or 0.005 [0.13] whichever is greater
Individual defect – maximum depth	0.07 T or 0.030 [0.76] whichever is less	0.10 T or 0.050 [1.3] whichever is less	0.20 T or 0.070 [1.8] whichever is less
Accumulated length in any 3 in [75 mm] of weld – maximum	0.20 [5.1]	0.60 [15]	1.00 [25]
Craters			
Maximum depth	0.20 T or 0.03 [0.8] whichever is less	0.20 T or 0.05 [1.3] whichever is less	0.20 T or 0.05 [1.3] whichever is less
Maximum length	1 T	1 T	2 T
Arc Strikes / Gouge Marks	Unacceptable	Unacceptable	No stated requirement

(Continued)

Table 7.1 (Continued)
Acceptance Criteria (in [mm])

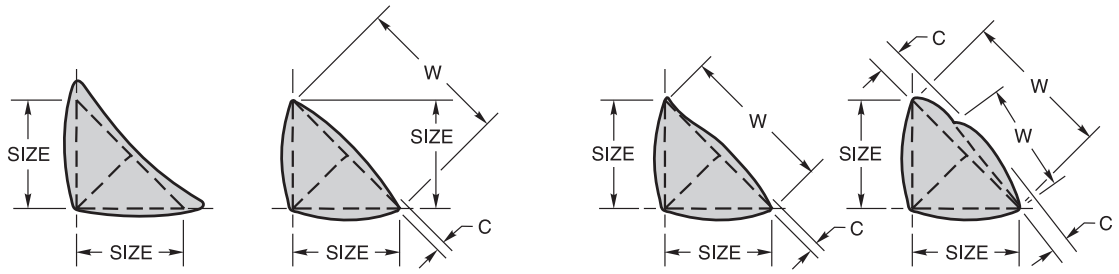
Discontinuity	Class A	Class B	Class C
Maximum Weld Reinforcement – machine welds			
Material to 0.375 [9.5] and under	1/3 T or 0.030 [0.76] whichever is greater	No stated requirement	No stated requirement
Material greater than 0.375 [9.5]	0.125 [3.2]	No stated requirement	No stated requirement
Melt-Through Welds	See Annex A	See Annex A	See Annex A
Maximum Weld Reinforcement—manual welds			
Material up to 0.125 [3]	1 T	No stated requirement	No stated requirement
Material over 0.125 to 0.510 [3 to 13]	1/3 T or 0.100 [2.5], whichever is greater	No stated requirement	No stated requirement
Material greater than 0.510 [12.9]	0.170 [4.3]	No stated requirement	No stated requirement
Mistmatch between Members after welding	Refer to Paragraph 7.3.2.1 & Figure 7.2. Includes A, B, & C Class of Welds		
Weld Profiles	Requirements of Figure 7.1	Requirements of Figure 7.1	Requirements of Figure 7.1
Angular Peaking	Requirements of 7.3.2.2	Requirements of 7.3.2.2	Requirements of 7.3.2.2
Fillet Weld Size – when fillet weld size is stated on the drawing			
Minimum size	As shown by the welding symbol	As shown by the welding symbol	As shown by the welding symbol
Fillet Weld Size – minimum size when fillet weld size is not stated on the drawing			
Minimum size – single side fillet	1.5 T	1.5 T	1.5 T
Minimum size – double side fillet	1 T	1 T	1 T
Fillet Weld Size – maximum			
Material up to 0.090 [2.3]	2 times the minimum fillet weld size	2 times the minimum fillet weld size	2 times the minimum fillet weld size
Material 0.091 to 0.156 [2.31 to 4.0]	1.5 times the minimum fillet weld size	1.5 times the minimum fillet weld size	1.5 times the minimum fillet weld size
Material 0.157 to 0.750 [4.01 to 19]	1.25 times the minimum fillet weld size	1.25 times the minimum fillet weld size	1.25 times the minimum fillet weld size
Material greater than 0.751 [19]	1.1 times the minimum fillet weld size	1.1 times the minimum fillet weld size	1.1 times the minimum fillet weld size
Discoloration[c]—Titanium			
Bright Silver	Acceptable	Acceptable	Acceptable
Silver	Acceptable[d]	Acceptable[d]	Acceptable[d]
Light Straw	Acceptable[d]	Acceptable[d]	Acceptable[d]
Dark Straw	Acceptable[d]	Acceptable[d]	Acceptable[d]
Bronze	Acceptable[d]	Acceptable[d]	Acceptable[d]
Brown	Acceptable[d]	Acceptable[d]	Acceptable[d]
Violet	Reject[f]	Acceptable[d]	Acceptable[d]
Blue	Reject[e]	Reject[f, e]	Reject[f, e]
Green	Reject[e]	Reject [f,h]	Reject[f,h]
Gray	Reject [g]	Reject [g]	Reject [g]
White	Reject [g]	Reject [g]	Reject [g]

(Continued)

Table 7.1 (Continued)
Acceptance Criteria (in [mm])

Discontinuity	Class A	Class B	Class C
Discoloration—Stainless Steel, Nickel, and Cobalt Alloys			
All oxidation colors, except for Black	Acceptable	Acceptable	Acceptable
Black discoloration or the presence of scale	Reject	Reject	Reject
Discoloration—Steel			
All oxidation colors, except for Black	Acceptable	Acceptable	Acceptable
Black	Reject	Reject	Reject

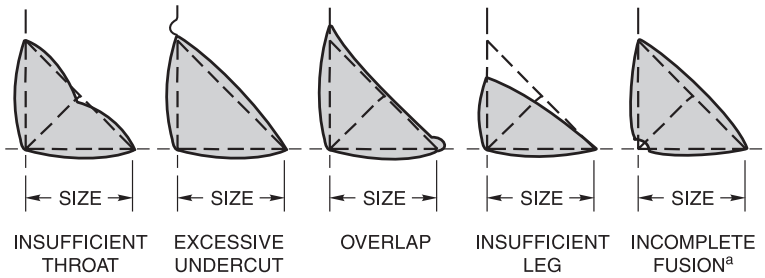
[a] For groove weld only.
[b] Discontinuity of size 0.005 in [0.13 mm] or less shall not be used in the determining compliance to the spacing requirements.
[c] Discoloration comes in various shades, tones, and hues.
[d] Discoloration must be removed prior to additional welding.
[e] On the weld and in the HAZ up to 0.030 in [0.76 mm] beyond the weld. This color is acceptable on base metal outside of 0.030 in [0.76 mm] from the toe of the weld.
[f] Blue and Green discoloration is rejectable if additional welding is to be performed. Blue and green discoloration is acceptable on finish welds but must be removed prior to subsequent processing per 6.15.1.
[g] Rejectable discoloration may be accepted if it can be proven that embrittlement has not occurred. This proof must be provided through direct testing, such as microhardness. Test method and acceptance criteria used for acceptance must be approved by the engineering authority.



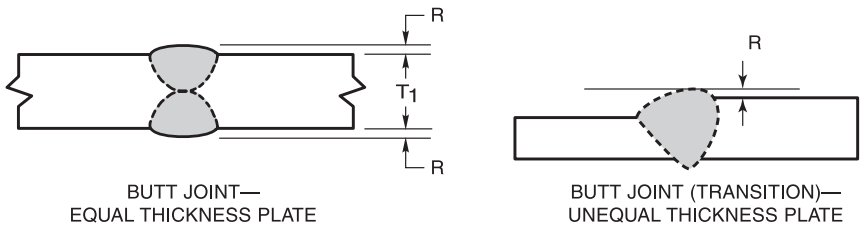
(A) DESIRABLE FILLET WELD PROFILES **(B) ACCEPTABLE FILLET WELD PROFILES**

Note: Convexity, C, of a weld or individual surface bead with dimension W shall not exceed the value of the following table:

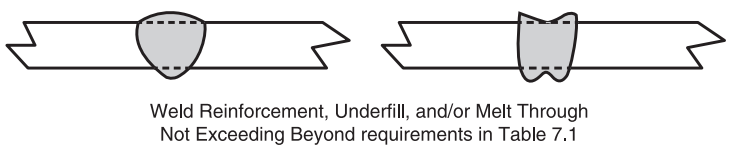
Width of Weld Face or Individual Surface Bead, W	Max Convexity, C
W ≤ 5/16 in [7.9 mm]	1/2 W or 1/16 in [1.6 mm], whichever is less
W > 5/16 in [7.9 mm] TO W < 1 in [25 mm]	1/8 in [3.2 mm]
W ≥ 1 in [25 mm]	3/16 in [4.8 mm]



(C) UNACCEPTABLE FILLET WELD PROFILES

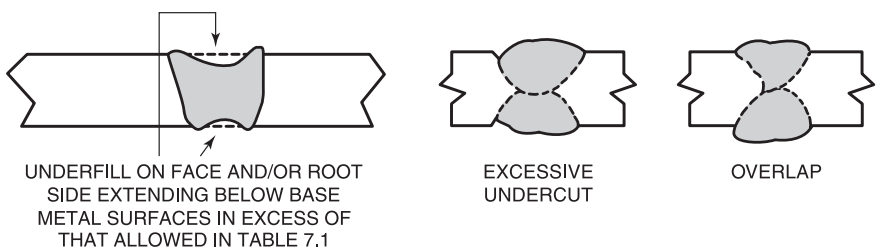


Note: Reinforcement R shall not exceed the value specified in Table 7.1



Weld Reinforcement, Underfill, and/or Melt Through
Not Exceeding Beyond requirements in Table 7.1

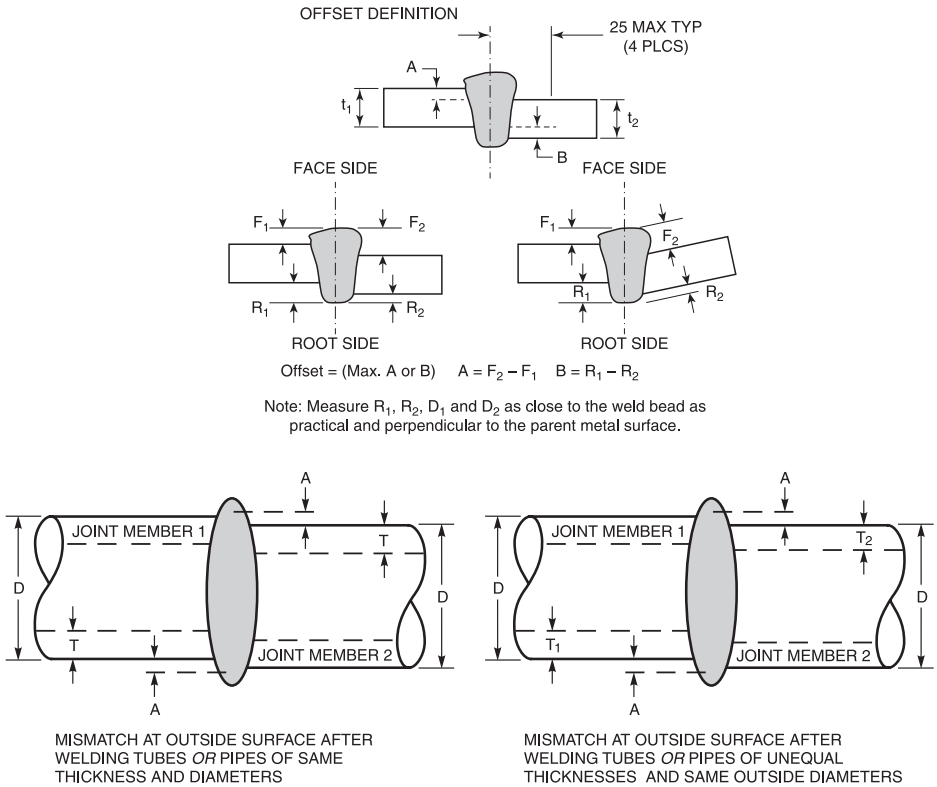
(D) ACCEPTABLE GROOVE WELD PROFILE IN BUTT JOINT


UNDERFILL ON FACE AND/OR ROOT SIDE EXTENDING BELOW BASE METAL SURFACES IN EXCESS OF THAT ALLOWED IN TABLE 7.1
EXCESSIVE UNDERCUT
OVERLAP

[a] Refer to 5.4.8.2

(E) UNACCEPTABLE GROOVE WELD PROFILES IN BUTT JOINTS

Figure 7.1—Acceptable and Unacceptable Weld Profiles



Note: Dimension 'A' in above figures shall comply with the table. Refer to 7.4.2.1

Welding Process	Thickness of Thinnest	Mismatch
	'T'	'A' (Maximum)
OFW, SMAW, GTAW, GMAW, PAW, VP-PAW, FCAW, SAW	T ≤ 0.125 in [3 mm]	T or 0.040 in [1.0 mm], whichever is less
	T > 0.125 in [3 mm]	0.040 in [1.0 mm]
LASER AND ELECTRON BEAM	T ≤ 0.250 in [6 mm]	0.010 in + 0.1 × T [0.25 mm + 0.1 × T]
	T > 0.250 in [6 mm]	0.040 in [1.0 mm]

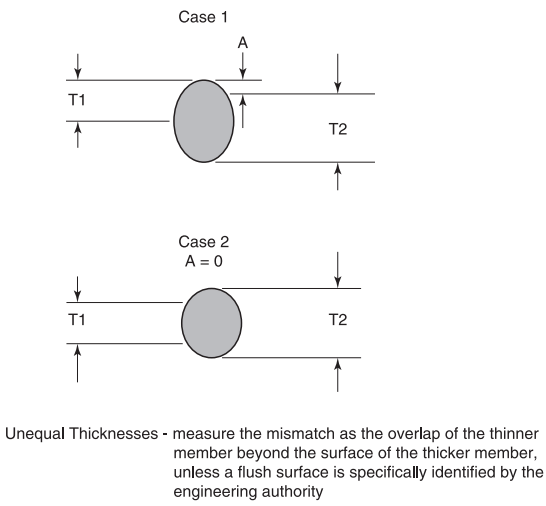

Case 1
A
T1
T2
Case 2
A = 0
T1
T2
Unequal Thicknesses - measure the mismatch as the overlap of the thinner member beyond the surface of the thicker member, unless a flush surface is specifically identified by the engineering authority

Figure 7.2—Mismatch Between Joint Members After Welding

8. Repair of Existing Structures

8.1 Scope. This clause of the specification provides the requirements and applicability for weld repair procedures. Additionally, this clause applies only to the weld repair of in-service (existing) aerospace flight hardware and shall not be used for corrections encountered during original manufacturing. Welding procedure specifications used for the repair of existing structures and components shall meet the requirements of government approved Original Equipment Manufacturers (OEMs) or the appropriate repair manuals. Depending on the criticality of the weld repair, the stress analysis of the repair area and the repair procedure shall be approved by the appropriate governmental agency prior to weld repair.

8.2 Design. Repairs to existing structures shall be performed in accordance with the current regulatory requirements. Welding procedures and stress analysis are required for critical and semicritical structures. Documentation of stress analysis results shall be made available to the customer as defined by contract, or 7 years, whichever is longer.

8.2.1 Classification. The Engineering Authority shall classify the repair weld by considering the process controls, inspection, and acceptance criteria as described in Clause 1.4 of this specification. The classification selected may be more stringent than the original design but shall not be classified to lesser than the original design unless both a stress analysis and mechanical testing data or component qualification has been performed. The stress analysis supporting the reduction of the weld classification shall be approved by the Engineering Authority per 8.2.

8.2.2 Structures. Structures are defined by the Engineering Authority according to accepted practices and shall have the same meaning herein.

8.2.2.1 Critical. Welds made to critical structures shall have a stress analysis performed to determine the adequacy of the repair based on the location of the weld and type of weld. Consideration shall be given to prevent the weld from becoming a metallurgical or mechanical notch in critical structures.

8.2.2.2 Semicritical. Welds made to semicritical structures shall have a stress analysis performed prior to welding the structure.

8.2.2.3 Noncritical. Welds used for the repair of noncritical structures may have a stress analysis performed at the discretion of the Engineering Authority. Consideration should be given to performing a stress analysis if the weld repair is located in an area that may cause failure of the noncritical structure or loss of performance to the system.

NOTE: Welds used for the repair of noncritical structures may have a stress analysis performed at the discretion of the Engineering Authority. Consideration should be given to performing a stress analysis if the weld repair is located in an area that may cause failure of the noncritical structure or loss of performance to the system.

8.3 Welding Procedures

8.3.1 Qualification. Welding procedures shall be qualified per Clause 5, and as modified herein. A previously qualified weld procedure may have the qualification extended for repair welding when authorized by the Engineering Authority.

8.3.1.1 Procedure qualifications for weld repair of critical and semicritical structures shall be limited to the same base metal type, filler metal, and welding process used for the actual repair.

8.3.1.2 Qualifying a welding procedure for weld repair of noncritical structures may be required at the discretion of the Engineering Authority.

8.3.2 Techniques. Welding techniques that contribute to the required design strength shall be included as qualification variables of the weld repair procedure of critical and semicritical structures. This includes, but is not limited to specifying and changing any of the following variables:

(1) Qualification parameters or heat input

(2) Bead width

(3) Reinforcement

(4) Welding sequence

(5) Position

(6) Filler metal strength

(7) Process

(8) Preweld and postweld heat treatments or aging

(9) Preheat and interpass temperatures

Welding procedures that require qualification for purposes of developing a special technique shall have the welding techniques described in detail and shall become a part of the qualification variables of the welding procedure subject to requalification.

8.4 Welder and Welding Operator Qualification. Welders and Welding Operators shall be qualified per Clause 5 to perform welding using the equipment specified by the welding procedure.

8.5 Welding Equipment. Welding equipment shall meet the requirements of 6.3.

8.6 Weld Repair Inspection. Repair welding acceptance criteria shall be defined by the Engineering Authority or service manuals. As a minimum, the repair weld and the area within 0.5 in [13 mm] of the repair weld shall be inspected.

8.6.1 Visual Weld Inspection. All repair welds shall have a visual inspection performed by qualified personnel prior to performing other NDE techniques.

8.6.2 Surface Inspections. All repair welds shall have a final PT or MT inspection in accordance with the appropriate industry or customer specification (contingent upon magnetic properties regardless of criticality).

8.6.3 Internal Inspection. All repair welds to critical and semicritical structures regardless of the class of the weld shall have either RT or UT performed in accordance with the appropriate industry or customer specification.

8.7 Grounding and Bonding. Prior to welding on aircraft, an electrical ground path shall be approved by the Engineering Authority.

8.8 Repair Documentation

8.8.1 All repair welds made to critical and semicritical structures shall be documented with the following information:

(1) Location(s) (Drawing Number that will adequately identify the structure, using frame number, distance from identifiable lofting dimensions, etc.)

(2) Repair dimensions and extent of repair(s)

(3) Base and filler metal(s)

(4) Process(es)

(5) Procedure(s)

(6) Welder(s)

(7) Inspection method(s) and result(s)

8.8.2 Record Maintenance. Records of weld repairs shall be maintained in accordance with the requirements of the appropriate regulatory agency.

9. Nonflight Hardware

9.1 Scope. This clause establishes the minimum requirements for the design and fusion welding of nonflight hardware, with the exception of pressure vessels. One of the following three options shall be used in the implementation of this clause, as determined by the Engineering Authority:

(1) The codes and specifications listed in Table 9.1.

(2) The codes and specifications listed in Table 9.1 with the exceptions and additions specified in this clause.

(3) The requirements of Clauses 4–7 of this specification, with the exceptions and additions specified in Clause 9.

9.2 Exceptions and Additional Requirements. The following exceptions and additions are to be used with the applicable codes and specifications listed in Table 9.1, or with the requirements of Clauses 4–7 of this specification, when either option has been specified by the Engineering Authority.

Table 9.1
Industrial Codes and Specifications Suggested for Welding Aerospace Nonflight Hardware

Specification	Title
AWS D1.1/D1.1M	Structural Welding Code—Steel
AWS D1.2/D1.2M	Structural Welding Code—Aluminum
AWS D1.3/D1.3M	Structural Welding Code—Sheet Metal
AWS D1.4/D1.4M	Structural Welding Code—Reinforcing Steel
AWS D1.5M/D1.5	Bridge Welding Code
AWS D1.6/D1.6M	Structural Welding Code—Stainless Steel
AWS D1.9/D1.9M	Structural Welding Code—Titanium
AWS D3.6M	Specification for Underwater Welding
AWS D9.1M/D9.1	Sheet Metal Welding Code
AWS D14.1/D14.1M	Specification for Welding Industrial and Mill Crane and Other Material Handling Equipment
AWS D14.3/D14.3M	Specification for Welding Earthmoving, Construction, and Agricultural Equipment
AWS D14.4/D14.4M	Specification for Welded Joints in Machinery and Equipment
AWS D14.5/D14.5M	Specification for Welding of Presses and Press Components
AWS D14.6/D14.6M	Specification for Welding of Rotating Elements of Equipment
AWS D14.7/D14.7M	Recommended Practice for Surfacing and Reconditioning of Industrial Mill Rolls
AWS D14.8M (ISO/TR17844:2004 IDT)	Standard Methods for the Avoidance of Cold Cracks
AWS D15.1/D15.1M	Railroad Welding Specification for Cars and Locomotives
ASME B31.1	Code for Pressure Piping
ASME B31.3	Process Piping
AWWA STD 100	Standard for Welded Steel-Elevated Tanks, Standpipes, and Reservoirs for Water Storage American

9.2.1 Joint Classifications. The Engineering Authority shall specify the required weld design and inspection classification(s) on the engineering drawing. For structural welds, the design classifications shall be in accordance with the appropriate code or specification listed in Table 9.1, while the inspection classification shall be as follows: Class A, Class B, or Class C, in accordance with Clause 9.2.4.4. For welds in pressurized piping and tubing, the design and inspection classifications shall be in accordance with the applicable code or specification listed in Table 9.1 and with 9.2.4.4. The supplemental requirements of 9.2.4.4 pertain to the level of inspection required; the inspection procedures and acceptance criteria shall be in accordance with the applicable code or specification listed in Table 9.1. In cases where the codes and specifications in Table 9.1 do not address the specific materials being welded, Table 7.1 may be used for determining the inspection acceptance criteria.

9.2.2 Qualification

9.2.2.1 General Requirements. The fabricator shall be responsible for qualification of welders, welding operators, tack welders, and welding procedures prior to engaging in tacking and welding operations. Welders, welding operators, and tack welders may be qualified by the fabricator or an independent testing agency.

9.2.2.2 Performance Qualification. As an alternate to the requirements of the codes and specifications listed in Table 9.1, welders, welding operators, and tack welders engaged in the structural welding of nonflight hardware may be qualified in accordance with AWS B2.1.

NOTE: This alternative does not extend to welders, welding operators, and tack welders engaged in the welding of pressurized piping and tubing in accordance with any applicable clause of ASME B31.1 or B31.3.

9.2.2.3 Procedure Qualification. As an alternate to the requirements of the codes and specifications listed in Table 9.1, welding procedures to be used for the fabrication of Class A and Class B structural welds in nonflight hardware may be qualified in accordance with AWS B2.1.

NOTE: This alternative does not extend to welding procedures used for the welding of pressurized piping and tubing in accordance with any applicable clause of ASME B31.1 or B31.3.

9.2.3 Fabrication

9.2.3.1 Calibration. Welding equipment calibration requirements for automatic, mechanized, or robotic welding apparatus shall be in accordance with 6.3.1.

9.2.3.2 Welding Consumables

(1) **Identification**. The identification requirements for welding consumables shall be in accordance with 6.2.1.

(2) **Storage**. The storage requirements for welding consumables shall be in accordance with 6.2.2.

(3) **Consumable Inserts**. Consumable inserts shall be in accordance with AWS A5.30. Consumable inserts shall be of the same nominal composition as the filler metal to be used. No additional filler metal shall be added to a root pass when using a consumable insert.

(4) **Backing Rings in Pipe and Tubing for Fluid Applications**. With the exception of welds designated for ASME B31.3, Category D fluid service, backing rings shall not be used.

(5) **Shielding and Backing Gas**. Shielding and backing gas requirements shall be in accordance with 6.2.3, and as follows: Inert gas backing is required for all joints when consumable inserts are used. The root of full penetration welds shall be suitably protected from oxidation or atmospheric contamination for the following material groups: aluminum, aluminum alloys, nickel, nickel alloys, stainless steels, titanium, and titanium alloys.

Inert gas backing should be maintained for the root pass and subsequent passes until the joint is completed, or a minimum of 0.2 in [5 mm] of weld metal thickness has been deposited.

9.2.3.3 Preweld and Interpass Cleaning. Preweld and interpass cleaning requirements shall be in accordance with 6.5.

9.2.3.4 Preheating, Interpass Heating, and Postweld Heating. Heating and maintaining the proper temperature specified on the engineering drawing or by the WPS may be accomplished by any suitable method capable of providing a uniform temperature throughout the part for a distance at least equal to the thickness of the thickest member (but not less than 3 in [75 mm] in all directions from the point of welding. For field applications, it is preferred that induction coils or resistance heating braided "blankets" be used. When preheating is required, the joint shall be preheated prior to any welding, including tack welding. Temperatures shall be measured by suitable temperature-indicating methods that are accurate within ±25°F [14°C].

9.2.3.5 Filler Metals. Filler metal requirements shall be in accordance with 6.12.

9.2.3.6 Tack Welds. Tack welds shall be used as required and shall be made by a qualified welder, welding operator, or tack welder. Tack welds shall be spaced symmetrically around or along the joint whenever possible. Chipping or grinding shall be blended to fair smoothly with the base metal. Tack welds that contain cracks or visible porosity shall not be fused with the root pass and shall be removed in accordance with 9.2.5.1.

9.2.3.7 Weld Bead Initiation and Termination. Weld start and run-off tabs shall be used whenever a weld pass meets the end of a joint, with exception as approved prior to fabrication by the Engineering Authority. Weld tabs shall be made of the same material as the parts being welded. When start or run-off tabs cannot be used, the areas of initiation and termination of each weld bead shall be chipped or ground as necessary to remove any visible defects in the weld metal before depositing any subsequent weld beads. In addition, ground area shall be blended to fair smoothly with the adjacent base metal. Unless otherwise specified by the Engineering Authority, weld beads shall not terminate at inside corners or notches, or in other critical areas such as changes in welding direction or sudden changes in section thickness. For reference purposes, the point of termination is located where the weld metal protrudes furthest along the joint line.

9.2.3.8 Backgouging. All groove welded joints that are to be welded from both sides and require 100% penetration shall be back gouged to sound metal prior to the welding of the second side. Whenever possible, two or three passes shall be deposited on the first side prior to the gouging of the backside. Backgouging to sound metal may be done by machining, chisel, grinder, arc gouging, or by other appropriate methods. Gouged areas shall blended to fair smoothly with the adjacent metal.

9.2.3.9 Postweld Cleaning. Postweld cleaning requirements shall be in accordance with 6.15.

9.2.3.10 Identification of Welds. Appropriate records shall be maintained that identify the welds made by each qualified welder and welding operator. These records shall be made available to the Engineering Authority when required by contract documentation.

9.2.4 Inspection

9.2.4.1 General. The fabricator is responsible for the performance of all inspections, tests, and quality control requirements as specified herein. The fabricator may utilize his own or any other testing laboratory acceptable to and approved by the Engineering Authority for the performance of all required destructive and nondestructive inspections.

The visual and nondestructive inspections described herein shall apply to completed welds and the adjacent base metal up to a minimum of 0.5 in [13 mm] from both sides of the edge of the deposited weld metal. Welds that do not satisfy the acceptance criteria of the appropriate code or specification listed in Table 9.1 shall be reworked in accordance with 9.2.5.

9.2.4.2 Qualification of NDE Personnel. NDE personnel qualification requirements shall be in accordance with 7.1.

9.2.4.3 Visual Inspection. All welds shall be visually inspected for conformation to the drawing requirements and to the requirements of either the appropriate code or specification listed in Table 9.1, or the requirements of Table 7.1.

9.2.4.4 NDE of Nonflight Hardware

(1) **Class A Inspection (for structural welds only)**. In addition to the required visual inspection, all Class A inspections shall require 100% radiographic testing (RT) and either 100% magnetic particle testing (MT) or 100% liquid penetrant testing (PT) in accordance with the appropriate codes or specifications listed in Table 9.1. Ultrasonic testing (UT) may be used in lieu of RT at the Engineering Authority's discretion.

(2) **Class B Inspection (for structural welds only)**. In addition to the required visual inspection, all Class B inspections shall require either 100% MT or 100% PT in accordance with the appropriate codes or specifications listed in Table 9.1. When producing multipass welds in thick sections, it is recommended that the root pass, final pass, and each 0.5 in [13 mm] interval of thickness be inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection. RT may be used at the Engineering Authority's discretion.

(3) **Class C Inspection (for structural welds only)**. All Class C inspections require only the visual inspection described in 9.2.4.3. MT and/or PT may be used at the Engineering Authority's discretion.

(4) **Welds in Piping and Tubing for Fluid Service**. When this specification is used in conjunction with ASME B31.3 only, all piping and tubing welds shall undergo NDE in accordance with the following paragraphs in addition to the required visual inspections:

(a) **Normal Fluid Service**. All welds classified for Normal Fluid Service shall require 10% random RT; if any of the tested welds are found to be unacceptable, an additional randomly selected 10% (minimum) of the production welds shall be tested. If any of the tested welds in the second sampling are found to be unacceptable, then a 100% inspection of the remaining production welds is required.

(b) **Severe Cyclic Conditions**. All welds classified as subjected to Severe Cyclic Conditions shall require 100% RT and either 100% PT or 100% MT.

(c) **Category M Fluid Service**. All welds classified for Category M Fluid Service shall require 100% RT and either 100% PT or 100% MT.

(d) **High Pressure Fluid Service**. All welds classified for High-Pressure Fluid Service shall require 100% RT and either 100% PT or 100% MT.

(e) **Category D Fluid Service**. All welds classified for Category D Fluid Service shall require either 100% MT or 100% PT.

(5) **In-Process Examination for Automatic Gas Tungsten Arc Welding (GTAW)**. With the exception of welds designated for High Pressure and Category M Fluid Service per ASME B31.3, an in-process examination may be substituted for the required RT of piping and tubing welds made using a fully automatic GTAW process only. In addition to the in-process examination requirements defined in ASME B31.3, the following additional requirements shall be satisfied:

(a) The in-process examination shall be applied to all welds.

(b) The automatic GTAW process parameters shall be strictly monitored and recorded; if these parameters exceed plus or minus 10% of the qualified values established during the welding procedure qualification, the affected weld shall require RT. The process parameters to be monitored and recorded shall include the following:

(i) Arc current

(ii) Pulse high current

(iii) Pulse low current

(iv) Pulse high time

(v) Pulse low time

(vi) Start slope

(vii) Finish slope

(viii) Rotation delay

(ix) Head speed (rpm)

(x) Shielding and backing gas flow rate

(xi) Arc voltage

(xii) Tungsten electrode (position, length, bevel, land, arc length)

(c) Welds classified as subjected to Severe Cyclic Conditions shall require 100% PT or 100% MT.

NOTE: All NDE materials (e.g., liquid penetrants, developers, ultrasonic couplants, etc.) that are to be applied to surfaces that will be exposed to oxygen (gaseous or liquid) or hypergols in-service shall be compatible with that service fluid. Oxygen compatibility shall be determined in accordance with procedures approved by the Engineering Authority.

9.2.4.5 Alternate Inspection Methods. In cases where the joint configuration makes it impractical to obtain a satisfactory radiograph (e.g., a fillet weld) a satisfactory alternate method of NDE shall be approved by the Engineering Authority. If PT or MT is proposed to be used in lieu of RT, then the root pass, final pass, and each 0.5 in [13 mm] interval of thickness shall be inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection. In cases where adequate postweld inspection cleaning is difficult to achieve (e.g., inner lines of vacuum-jacketed systems; intermediate passes of multipass welds in aluminum), PT may be selectively omitted if approved by the Engineering Authority (e.g., a visual inspection, RT, and a proof test of an inner line in a vacuum-jacketed cryogenic system could be considered sufficient without PT). Also, PT of just the final pass of a multipass aluminum weld could be considered sufficient. The necessity of selectively omitting PT, as well as the necessity and acceptability of any proposed alternate NDE methods, should be agreed upon by the fabricator and the Engineering Authority.

9.2.4.6 Proof Testing. Proof testing may be used in conjunction with or in lieu of the required NDE if approved by the Engineering Authority.

9.2.4.7 Etching for PT. Weldments in soft metals (i.e., aluminum alloys, magnesium alloys, etc.) that are machined, ground, sanded, abraded, or otherwise mechanically worked to cause smearing or disruption of the metal surface shall be etched to remove the masking material prior to penetrant application. Etching is not required for those features such as close tolerance surfaces, faying surfaces, etc., where the function of the component or assembly would be degraded.

9.2.4.8 Penetrant Testing (PT) Allowable Type. Welds may be penetrant tested using any approved Type I or II penetrant systems.

9.2.5 Weld Rework

9.2.5.1 Discontinuity Removal. Portions of weld and/or base metal containing rejectable discontinuities shall be removed to sound metal. The use of mechanical means (e.g., grinding, chipping, or machining) is preferred. After the removal of any metal containing discontinuities, and prior to re-welding, the joint shall be re-inspected to ensure that the discontinuities have been completely removed, using the same inspection method and acceptance criteria used to detect the original discontinuity.

9.2.5.2 Rework Procedure. The rework welding procedure shall be the same as the original qualified WPS or an approved qualified repair process, recognizing that the cavity to be repaired may differ in contour and dimensions from

the original joint. With the exception of Class C structural welds and Category D Fluid Service welds (per ASME B31.3), no more than two attempts shall be made to rework a weld discontinuity; further rework attempts require the approval of the Engineering Authority. The completed reworked weld shall be inspected to the same requirements and acceptance criteria as the original weld.

9.2.5.3 Rework Records. The fabricator shall prepare and maintain records of all weld reworks in Class A and B welds and shall make these records available to the Engineering Authority.

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Annex A (Normative)
Guidelines for Design, Analysis, and Fabrication of Weld Joints

This annex is part of this standard and includes mandatory elements for use with this standard.

A1. Scope

The following information and figures are provided as standard design information. These joint designs and dimensions are based on widespread use in the aerospace industry with satisfactory results. However, it is incumbent upon the Engineering Authority that if these designs are used sufficient engineering analysis is performed for the application.

Fabricators—The Engineering Authority may require fabricators to comply with the requirements of this Annex for fitup.

A2. Groove Welds

The designer may use the standard joint details given in Figure A.1 for complete joint penetration groove welds and Figure A.2 for complete penetration groove welds in two- and three-piece tee joints.

A2.1 Groove Weld Effective Area. The effective area is the effective weld length multiplied by the weld size. The effective weld length for any groove weld, perpendicular or nonperpendicular (square or skewed), should be the width of the part joined perpendicular to the direction of stress. The weld size of a complete joint penetration groove weld should be the thickness of the thinner part joined. Weld reinforcements do not increase the effective area of the weld.

A3. Edge Welds in Flanged Joints

A3.1 The designer may use the standard joint details given in Figure A.3.

A4. Fillet Welds

A4.1 Fillet Weld Size. The efficiency of the weld joint is based on the strength of the weaker member being joined. It is based on member thickness multiplied by the base metal ultimate tensile strength. To achieve 100% joint efficiency using an equivalent strength filler metal the weld size must be a minimum of 70% of the base metal thickness for a double-sided weld, and 140% for a single-sided weld. The suggested minimum weld size for a single fillet weld is 1.5 times the thickness of the thinner member being joined. The suggested minimum weld size for double fillet welds is 1.0 times the thickness of the thinner member being joined. However, when dynamic loading conditions are present, the Engineering Authority should assure that the required fillet weld size is suitable for the design application.

For lap and corner joints, when the maximum size fillet weld is required, a convex fillet, the size of the thinnest member should be specified on the drawing (E = S). See Figure A.4.

The relationship of the effective throat to weld size is shown in Figure A.4. Correction factors for fillet welds in skewed T-joints are given in Table A.1 for dihedral angles (Ψ) between 60 degrees and 135 degrees.

A4.2 Fillet Weld Effective Throat

A4.2.1 Calculation. The effective throat of a fillet weld is the shortest distance from the joint root to the weld face. No strength allowance should be given in the design calculations for root penetration unless a combination groove and fillet weld is specified for the joint.

A4.2.2 Shear Stress. Stress on the effective throat of a fillet weld is considered as shear stress regardless of the load direction.

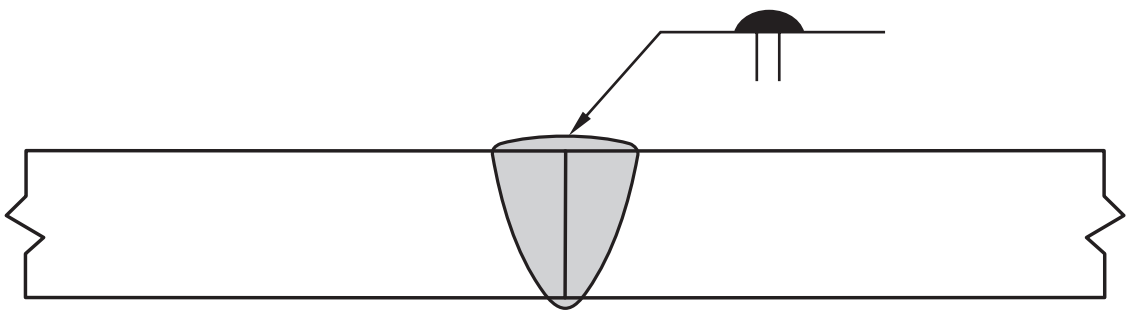
A4.3 Fillet Weld Length

A4.3.1 Effective Length (Straight). The effective length of a fillet weld should be the overall length of the full-size fillet including boxing. No reduction in effective length should be made for either the start of the weld or the end, in the design calculations.

A4.3.2 Effective Length (Curved). The effective length of a curved fillet weld should be measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or a slot computed from this length is greater than the area of the hole in the plane of the faying surface, then the area of the hole should be used as the effective area of the fillet weld.

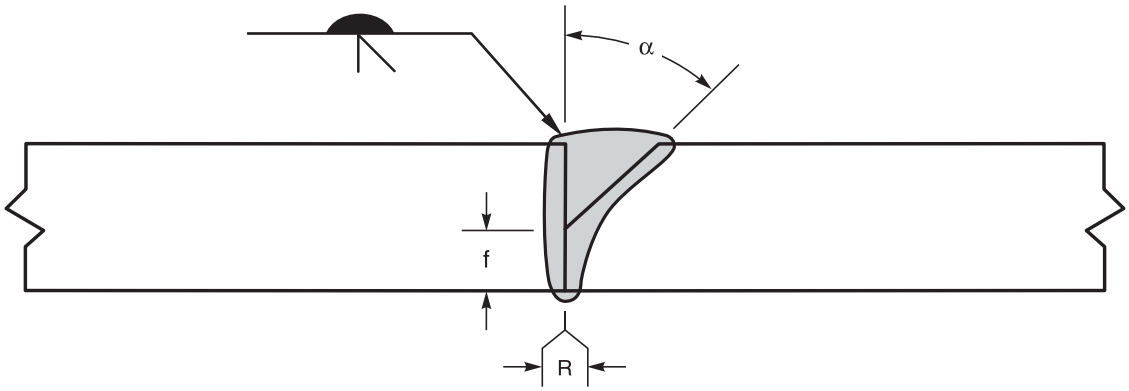
A4.3.3 Fillet Weld Minimum Length. The minimum effective length of a fillet weld should be at least four times the nominal size.

A4.4 Fillet Weld Effective Area. The effective area should be the effective length multiplied by the effective throat.



Weld Process	Base Metal Thickness "T" (in [mm])	Max Root Opening [R] (in [mm])	Material	Remarks
GTAW	0.090 [2.5] max	1/2 T or 0.045 [1.1], whichever is less	Any	Manual GTAW
	0.125 [3] max	1/4 T or 0.030 [0.76], whichever is less	Any	Mechanized GTAW
	0.250 [6] max		Al or Ti	Mechanized GTAW
PAW	0.375 [10] max	1/4 T or 0.030 [0.76], whichever is less	Al or Ti	Mechanized PAW
		0.040 [1.02] max	Al or Ti	Mechanized VP-PAW
EBW	≤0.030 [0.7] 0.031–0.100 [0.71–2.5] 0.101–0.200 [2.51–5] 0.201–0.300 [5.1–8] 0.301–0.400 [8.1–10] >0.400 [>10]	0.002 [0.051] 0.005 [0.13] 0.007 [0.18] 0.008 [0.20] 0.009 [0.23] 0.010 [0.25]	Any	
LBW		1/8 T or 0.005 [0.13], whichever is less	Any	

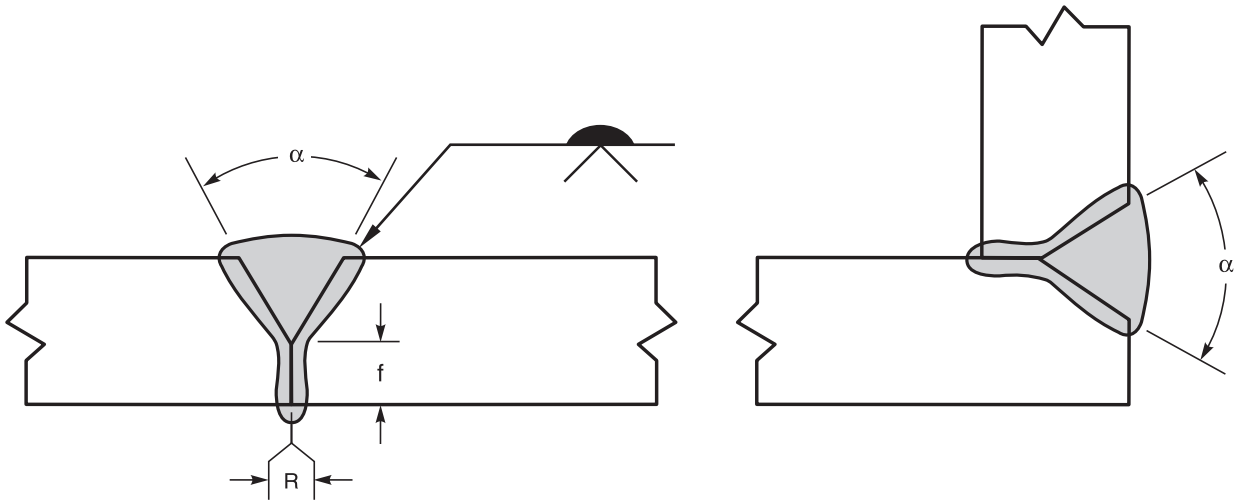
Figure A.1(a)—Square Groove Butt Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Root Opening [R] (in [mm]) Max.	Root Face [f] (in [mm])		Groove Angle [α] (degrees)	
GTAW	0.060–0.500 [1.5–13]	≤0.030 [0.76]	0.030 [0.76]	+0.030 [0.76] –0.000 [0.00]	60°	+10° –5°
PAW[a]	0.060–0.500 [1.5–13]	≤0.030 [0.76]	0.030 [0.76]	+0.030 [0.76] –0.000 [0.00]	60°	+10° –5°
GMAW FCAW SAW	0.060 [1.5] – unlimited	≤0.030 [0.76]	0.060 [1.52]	+0.030[0.76] –0.000 [0.00]	45° 60°	+10° [b] –5° [c]

[a] Non-keyhole mode only.
[b] Applicable to ferrous, heat resistant, and magnesium alloys.
[c] Applicable to aluminum and titanium alloys.

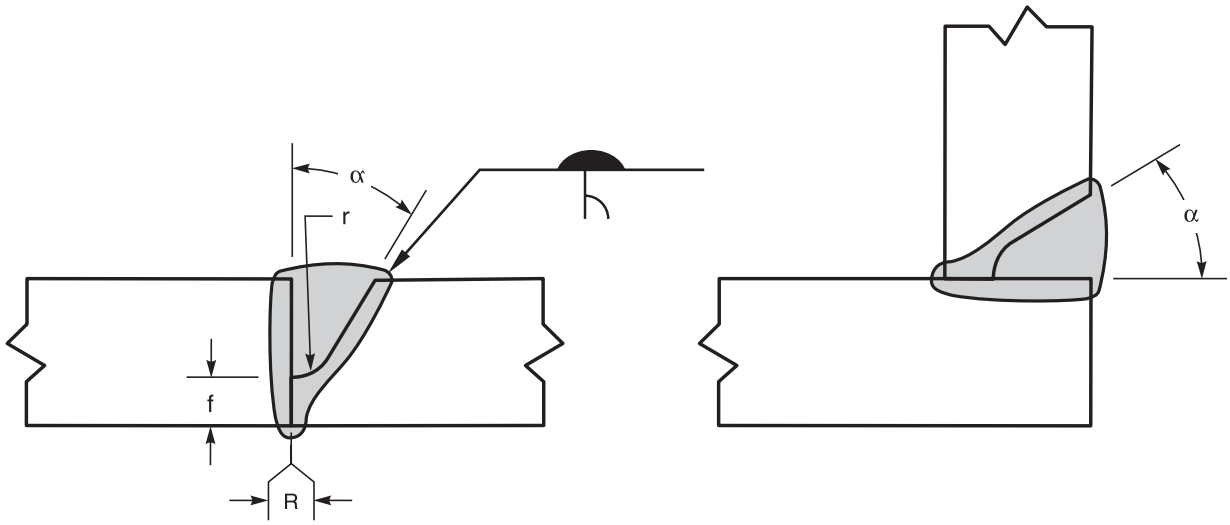
Figure A.1(b)—Single-Bevel-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Root Opening [R] (in [mm]) Max.	Root Face [f] (in [mm])		Groove Angle [α] (degrees)	
GTAW	0.060–0.500 [1.5–13]	≤0.030 [0.76]	0.030 [0.76]	+0.030 [0.76] –0.000 [0.00]	60°	+10° –5°
PAW[a]	0.060–0.500 [1.5–13]	≤0.030 [0.76]	0.030 [0.76]	+0.030 [0.76] –0.000 [0.00]	60°	+10° –5°
GMAW FCAW SAW	0.060 [1.5] – unlimited	≤0.030 [0.76]	0.060 [1.52]	+0.030[0.76] –0.000 [0.00]	45°	+10° –5°[b]
					60°	+10° –5°[c]

[a] Non-keyhole made only.
[b] Applicable to ferrous, heat-resistant alloys, and magnesium alloys.
[c] Applicable to aluminum and titanium alloys.

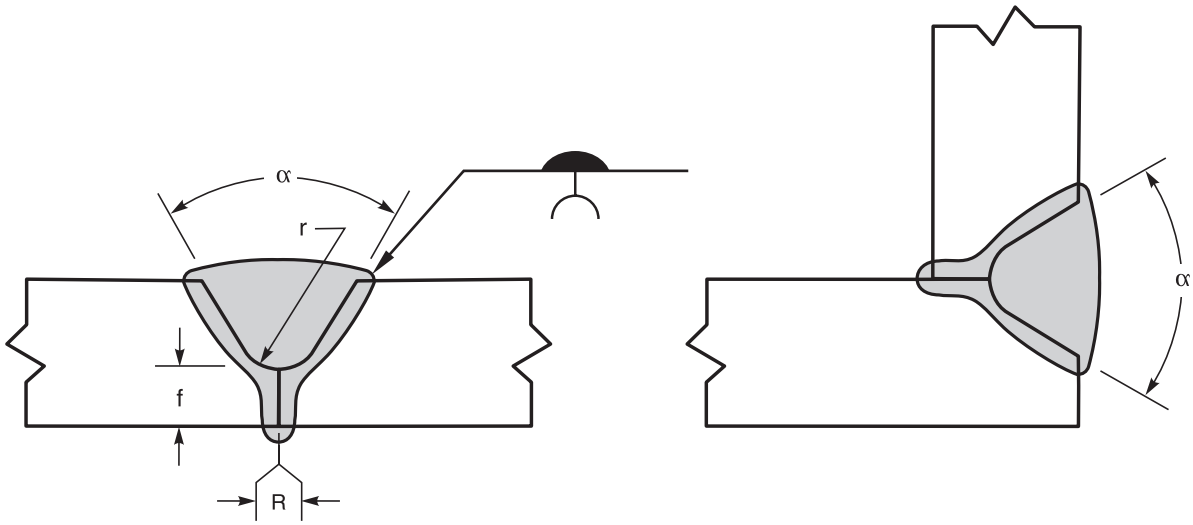
Figure A.1(c)—Single-V-Groove Weld Joints



Weld Process	Base Metal Thicknesss [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])	Groove Angle [α] (degrees)	Groove Radius (r) (in [mm])
GTAW	0.501–0.700 [13.1–18]	≤0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.000 [0.00]	30° +10° –5°	0.38 [9.7] 0.030 [0.76] –0.010 [0.25]
	>0.700 [18]	≤0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.000 [0.00]	30° +10° –5°	0.44 [11.2] +0.030 [0.76] –0.010 [0.25]
PAW[a]	0.501–0.700 [13.1–18]	≤0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.010 [0.025]	30° +10° –5°	0.38 [9.7] +0.030 [0.76] –0.010 [0.25]
	>0.700 [18]	≤0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.010 [0.025]	30° +10° –5°	0.44 [11.2] +0.030 [0.76] –0.010 [0.25]
GMAW FCAW SAW	0.501–0.700 [13.1–18]	≤0.030 [0.76]	0.060 [1.5] +0.030 [0.76] –0.030 [0.76]	30° +10° –5°	0.38 [9.7] +0.030 [0.76] –0.010 [0.25]
	>0.700 [18]	≤0.030 [0.76]	0.060 [1.5] +0.030 [0.76] –0.030 [0.76]	30° +10° –5°	0.44 [11.2] +0.030 [0.76] –0.010 [0.25]

[a] Non-keyhole mode only.

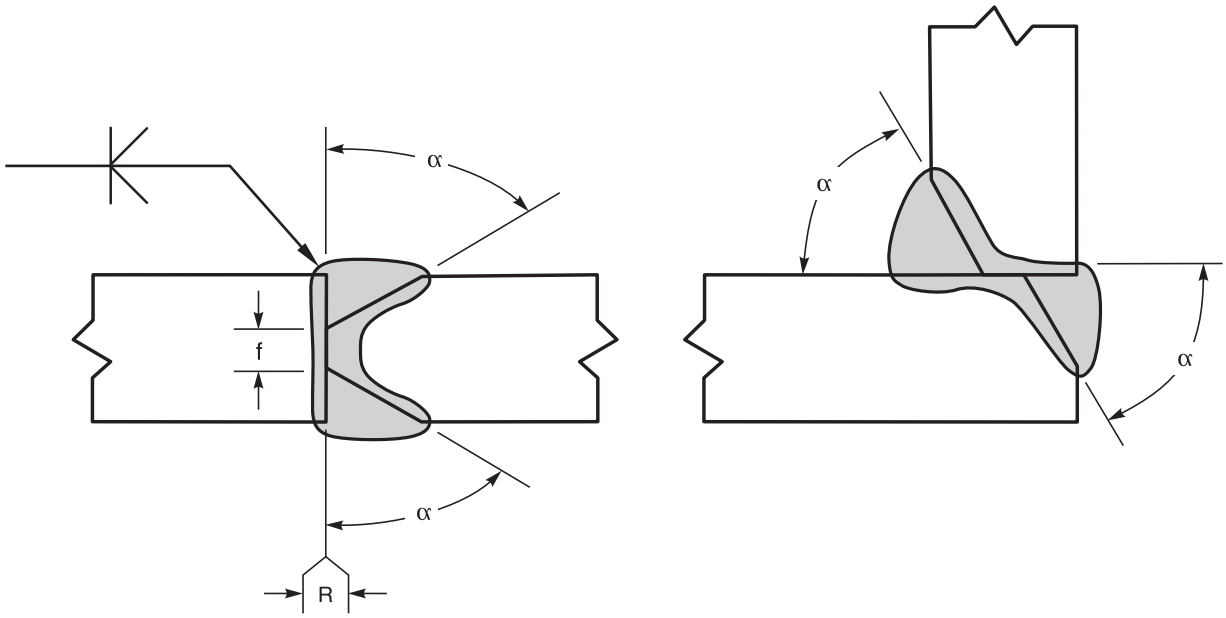
Figure A.1(d)—Single-J-Groove Weld Joints



Weld Process	Base Metal Thicknesss [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])	Groove Angle [α] (degrees)	Groove Radius (r) (in [mm])
GTAW	>0.400 [10]	≤0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.000 [0.00]	20° +10° –5°	0.250 [6] +0.030 [0.76] –0.010 [0.25]
PAW[a]	>0.400 [10]	≤0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.000 [0.00]	20° +10° –5°	0.250 [6] +0.030 [0.76] –0.010 [0.25]
GMAW FCAW SAW	>0.400 [10]	≤0.030 [0.76]	0.060 [1.5] +0.030 [0.76] –0.010 [0.25]	20° +10° –5°	0.250 [6] +0.030 [0.76] –0.010 [0.25]

[a] Non-keyhole mode only.

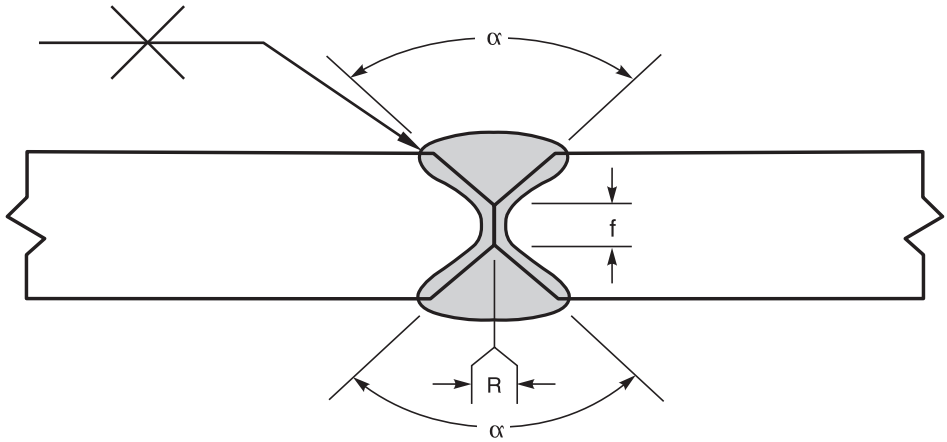
Figure A.1(e)—Single-U-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])[a]	Groove Angle [α] (degrees)
GTAW[b]	0.250–1.000 [6–25]	≤ 0.030 [0.76]	0.030 [0.76] + 0.030 [0.76] – 0.010 [0.25]	60° + 10° –5°
PAW[c,b]	0.250–1.000 [6–25]	≤ 0.030 [0.76]	0.030 [0.76] + 0.030 [0.76] – 0.010 [0.25]	60° + 10° – 5°
GMAW[b] FCAW SAW	0.250–1.000 [6–25]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	45° + 10° – 5° [d]
				60° + 10° – 5° [e]

[a] Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.
[b] Back-gouging to sound metal required before welding second side.
[c] Non-keyhole mode only.
[d] Applicable to ferrous, heat resistant, and magnesium alloys.
[e] Applicable to aluminum and titanium alloys.

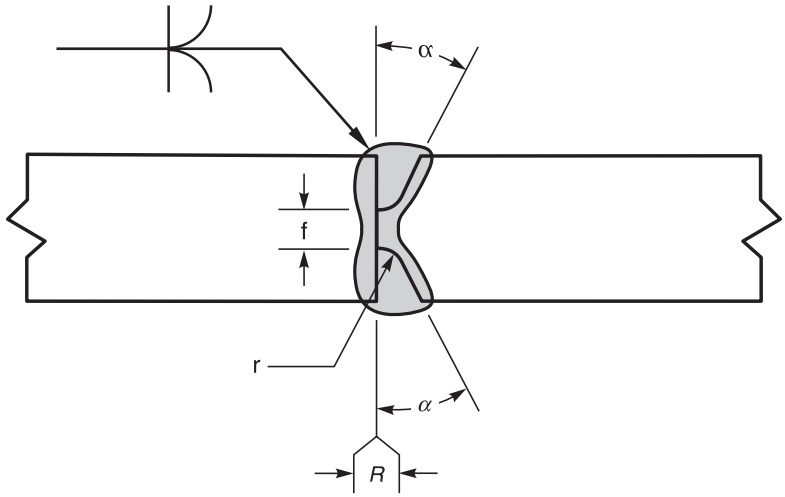
Figure A.1(f)—Double-Bevel-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])[a]	Groove Angle [á]
GTAW	0.250–1.000 [6–25]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.010 [0.25]	60° +10° –5°
PAW[b,c]	0.250–1.000 [6–25]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.010 [0.25]	60° +10° –5°
GMAW[c] FCAW SAW	0.250–1.000 [6–25]	≤ 0.030 [0.76]	0.060 [1.5] +0.030[0.76] –0.010 [0.25]	45° +10° –5°[d]
				60° +10° –5°[e]

[a] Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.
[b] Non-keyhole mode only.
[c] Backgouging to sound metal required before welding second side.
[d] Applicable to ferrous, heat resistant alloys, and magnesium alloys.
[e] Applicable to Aluminum and Titanium alloys.

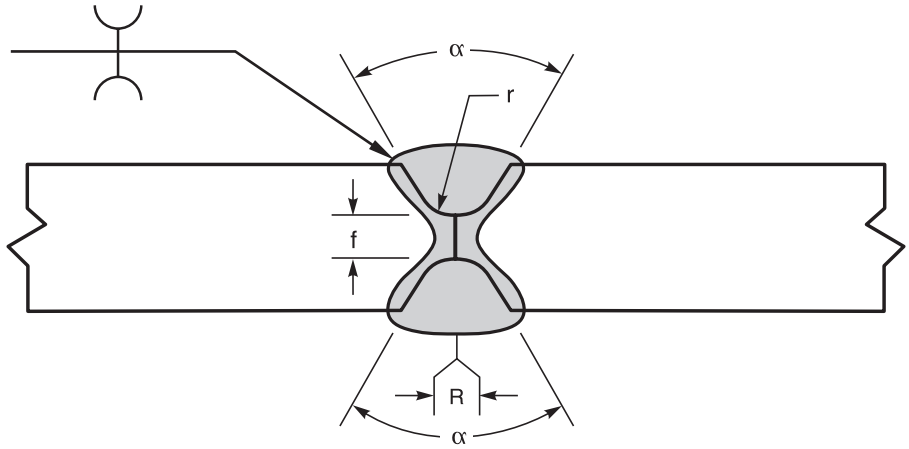
Figure A.1(g)—Double-V-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])[a]	Groove Angle [á]	Groove Radius [r] (in [mm])
GTAW[b]	0.501–1.400 [13.1–36]	≤ 0.030 [0.76]	0.040 [1.0] + 0.030 [0.76] – 0.010 [0.25]	30° +10° –5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
	≥ 1.400 [36]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	30° +10° –5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
PAW[c,b]	0.501–1.400 [13.1–36]	≤ 0.030 [0.76]	0.040 [1.0] + 0.030 [0.76] – 0.010 [0.25]	30° +10° –5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
	≥ 1.400 [36]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	30° +10° –5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
GMAW[b] FCAW	0.501–1.400 [13.1–36]	≤ 0.030 [0.76]	0.080 [2.0] + 0.030 [0.76] – 0.010 [0.25]	30° +10° –5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
SAW	≥ 1.400 [36]	≤ 0.030 [0.76]	0.120 [3.0] + 0.030 [0.76] – 0.010 [0.25]	30° +10° –5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]

[a] Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.
[b] Backgouging to sound metal required before welding second side.
[c] Non-keyhole mode only.

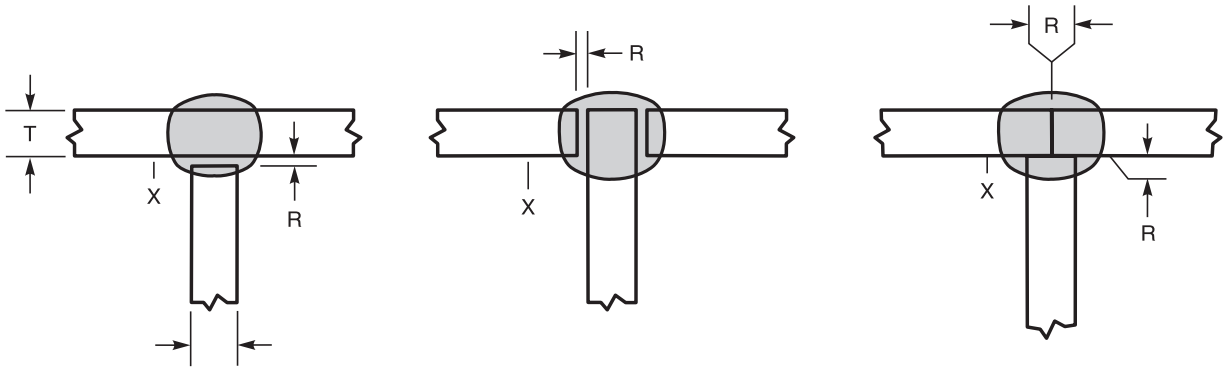
Figure A.1(h)—Double-J-Groove Weld Joints



Weld Process	Base Metal Thicknesss [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])[a]	Groove Angle [α]	Groove Radius (r) (in [mm])
GTAW[b]	0.501–0.800 [13.1-20]	≤0.030 [0.76]	0.040 [1.0] +0.030 [0.76] –0.010 [0.25]	20° +10° –5°	0.250 [6.35] +0.030 [0.76] –0.010 [0.25]
	>0.800 [>20]	≤0.030 [0.76]	0.060 [1.5] +0.030 [0.76] –0.010 [0.25]	20° +10° –5°	0.250 [6.35] +0.030 [0.76] –0.010 [0.25]
PAW[b,c]	0.501–0.800 [13.1-20]	≤0.030 [0.76]	0.040 [1.0] +0.030 [0.76] –0.010 [0.25]	20° +10° –5°	0.250 [6.35] +0.030 [0.76] –0.010 [0.25]
	>0.800 [>20]	≤0.030 [0.76]	0.060 [1.5] +0.030 [0.76] –0.010 [0.025]	20° +10° –5°	0.250 [6.35] +0.030 [0.76] –0.010 [0.025]
GMAW[c] FCAW SAW	0.501–0.800 [13.1-20]	≤0.030 [0.76]	0.080 [2.0] +0.030 [0.76] –0.010 [0.025]	20° +10° –5°	0.250 [6.35] +0.030 [0.76] –0.010 [0.025]
	>0.800 [>20]	≤0.030 [0.76]	0.120 [3.0] +0.030 [0.76] –0.010 [0.025]	20° +10° –5°	0.250 [6.35] +0.030 [0.76] –0.010 [0.025]

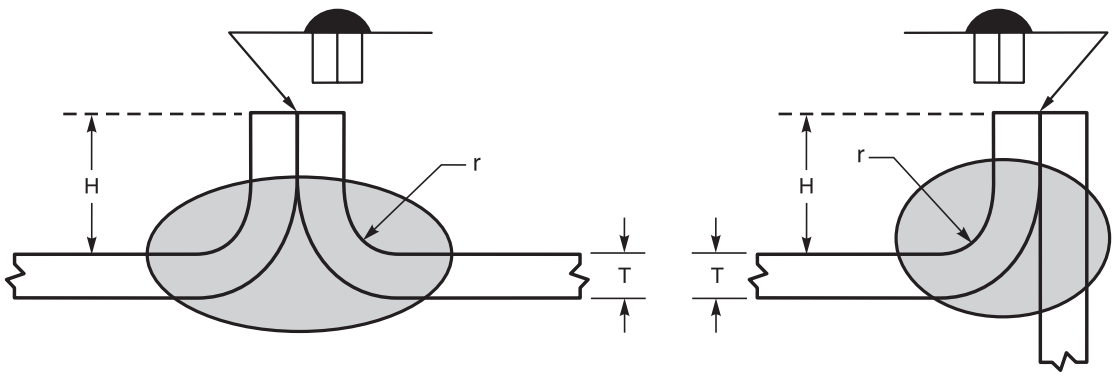
[a] Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.
[b] Backgouging to sound metal required before welding second side.
[c] Non-Keyhole mode only.

Figure A.1(i)—Double-U-Groove Weld Joints



Legend:
T = Thickness of thinner member
R = Root opening ≤ 0.010 in [0.25 mm] for T < 0.100 in [2.5 mm], ≤ 0.030 in [0.76 mm] for T ≥ 0.100 in [2.5 mm]
X = Weld Penetration
Min. = 1/2 T or 0.015 in [0.38 mm], whichever is greater
Max. = 2 1/2 T or 0.187 in [4.7 mm], whichever is less

Figure A.2—Two- and Three-Piece T-Weld Joints—Melt Through Welds

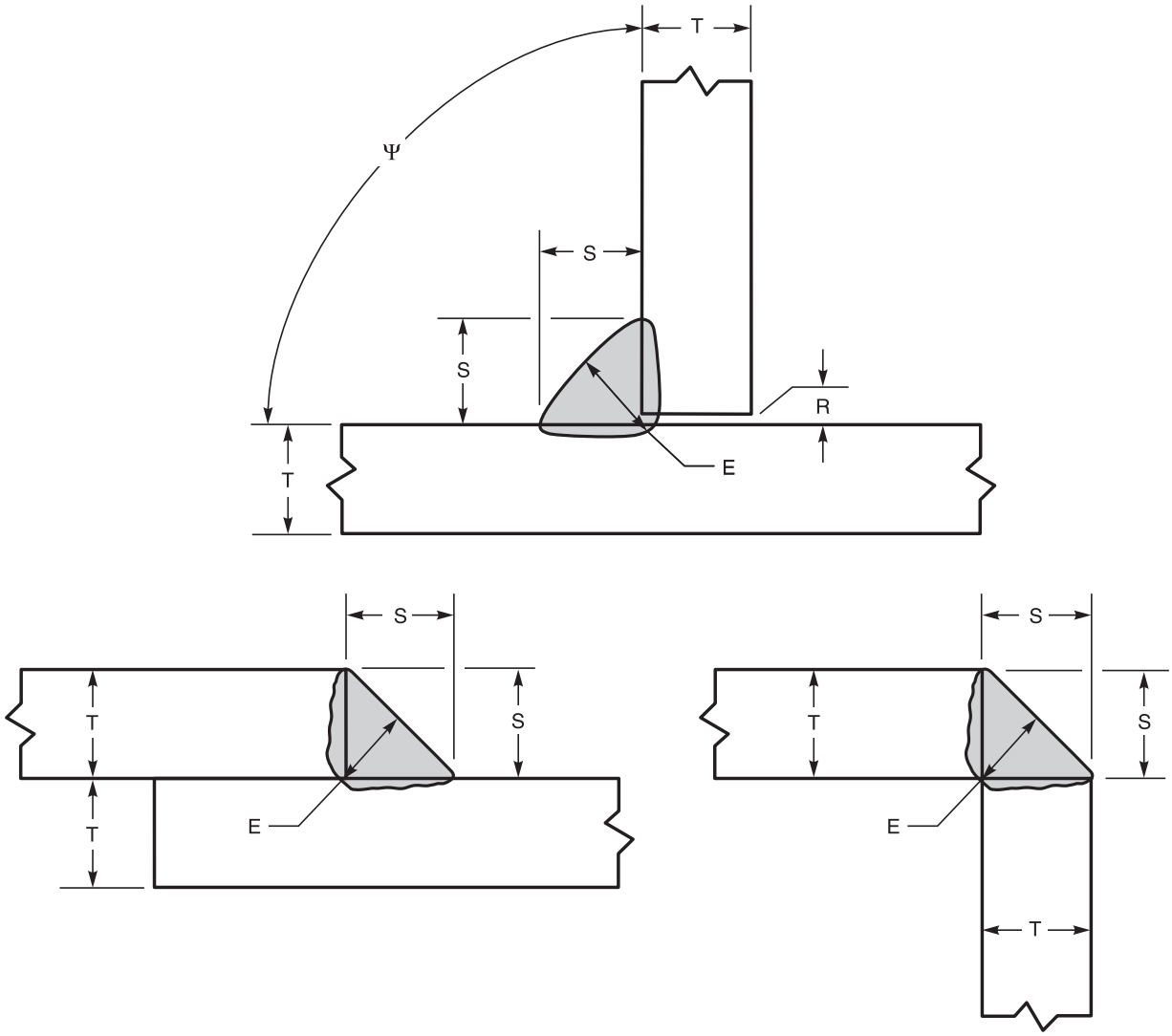


Thickness [T] In [mm]	Bend Radius [r] Max (in [mm])	Flange Height [H] (in [mm])
0.016—0.032 [0.4—0.8]	0.04 [1.0]	0.08—0.12 [2.0—3.0]
0.033—0.062 [0.81—1.5]	0.06 [1.5]	0.10—0.16 [2.5—4.1]
0.063—0.100 [1.51—2.5]	2T	0.12—0.20 [3.1—5.1]

Figure A.3 (a)—Flanged Joints

Base Metal	Base Metal Thickness [T] (in [mm])	Bend Radius [r] (in [mm])	Joggle [J] (in [mm])	Overlap [O] (in [mm])
Commercially Pure Titanium	0.020—0.040 [0.5—1.0]	0.04 [1.0] max.	T $^{+0.005\ [0.13]}_{-0.000\ [0.00]}$	0.032—0.060 [0.81—1.52]
Stainless Steel	0.020—0.063 [0.5—1.5]	0.04 [1.0] max.	T $^{+0.005\ [0.13]}_{-0.000\ [0.00]}$	0.032—0.090 [0.81—2.29]
Nickel	0.020—0.063 [0.5—1.5]	0.06 [1.5] max.	T $^{+0.005\ [0.13]}_{-0.000\ [0.00]}$	0.032—0.090 [0.81—2.29]

Figure A.3(b)—Flanged Edge Joints (Nonstandard)



Legend:
R = Root gap
T = Thickness of thinnest member
S = Minimum weld size
E = Minimum effective throat
Ψ = Skew angle
E min = 0.707T x factor(1)

Notes:
1. For corner or lap joints where full throat thickness is required: S min. = T min. where T equals thickness of thinner member.
2. For fillet weld size factor see Table A.1.

Figure A.4—Fillet Weld Details

Table A.1
Equivalent Fillet Weld Leg Size
for Skewed T-Joints

Dihedral Angle [Y]	Comparable Fillet Weld Size for Same Strength
60	0.71
65	0.76
70	0.81
75	0.86
80	0.91
85	0.96
90	1.00
95	1.03
100	1.08
105	1.12
110	1.16
115	1.19
120	1.23
125	1.25
130	1.28
135	1.31

Annex B (Normative)
Bend Testing Criteria

This annex is part of this standard and includes mandatory elements for use with this standard.

B1. Scope.

This annex covers the bend testing of groove and fillet welds. It provides the requirements for bend test specimen preparation, test parameters, testing procedures, bend radius requirements, and acceptance criteria. This annex shall be used when bend testing is the method to accept welder/operator qualification.

B2. Criteria for Bend Testing.

Bend testing may be used as an alternate to radiographic examination if the following conditions are met:

(1) The members of the test weld differ in thickness by less than 10 % of the thicker member.

(2) For tube welds, the outside diameter is equal to or more than 2 in [50 mm] in or the wall thickness is equal to or more than 0.250 in [6.35 mm].

(3) Alloy is not included in Table B.1. Alloys listed in Table B.1 shall be metallographic or radiographic examined in lieu of bend testing.

B3. Bend Testing.

Bend testing is required for all fillet welds with a base metal thickness of more than 0.063 in [1.6 mm], except that metallographic examination maybe used as an alternate to bend testing. The bend radius requirements are in Tables B.2 and B.2M. Bend testing of groove welds may be used as an alternate to radiographic examination as described in B.2. The bend test requirements for groove welds in tubes are in Table B.3.

B4. Acceptance Criteria.

B4.1 Groove welds. Groove weld bend specimens having open defects exceeding t or 1/8 in [3.2 mm], whichever is the lesser, on the convex surface are not acceptable.

B4.2 Fillet welds. Fillet weld bend specimens that exhibit less than complete fusion at the root of the joint are not acceptable. Figure 5.11 A illustrates the acceptable condition prior to bending and shall apply on the bend specimen.

Table B.1
Base Metals for Which Bend Testing is Not Applicable

Base Metal Group	Unified Number	Common Description
IA Carbon and Alloy Steels	K91122 K91283 K91313 K91472 K92810	9Ni–4Co steel 18Ni maraging steel
IB Heat Treatable Alloy Steels	All	
IIA Stainless Steels	S63198 S63199 R30155 R30590 S41800 S42000 S42200	19–9 DL 19–9 DX N155 S590 Greek Ascoloy 420 422
IIB Precipitation Hardenable Stainless Steels	All	
IIIB Precipitation Hardening Nickel and Nickel Base Alloys	All	
IV Aluminum Alloys	A03560 A92014 A92219	356 2014 2219
V Magnesium Alloys	All	
VI Titanium Alloys	R54620 R56210 R56260 R56620 R58640 NA NA	Ti–6Al–2Sn–4Zr–2Mo Ti–6Al–2Cb–1Ta–1Mo Ti–6Al–2Sn–4Zr–6Mo Ti–6Al–6V–2Sn Ti–3Al–8V–6Cr–4Mo–4Zr Ti–6Al–2Sn–2Zr–2Cr–2Mo Ti–15V–3Cr–3Mo–3Sn
VII Cobalt Base Alloys	All	

Table B.2
Bend Specimen Thickness and Bend Radius (in)

	Bend Specimen Thickness[a]					
	Unified Number (UNS)					
Bend Radius, A in[b]	R54520 R54810 R56320 R56400	A96061 A96063	R50400 R50550 R52400	R50250	A95083 A95086 A95456	Other
	$F = 12$[c]	$F = 8$	$F = 5$	$F = 4$	$F = 3$	$F = 2$
	≥ <	≥ <	≥ <	≥ <	≥ <	≥ <
0.070						0.031 0.035
0.079						0.035 0.039
0.088						0.039 0.044
0.099					0.029 0.033	0.044 0.050
0.111					0.033 0.037	0.050 0.056
0.125					0.037 0.042	0.056 0.062
0.140				0.031 0.035	0.042 0.047	0.062 0.070
0.157				0.035 0.039	0.047 0.052	0.070 0.078
0.176			0.031 0.035	0.039 0.044	0.052 0.059	0.078 0.088
0.198			0.035 0.040	0.044 0.049	0.059 0.066	0.088 0.099
0.222			0.040 0.044	0.049 0.055	0.066 0.074	0.099 0.111
0.249			0.044 0.050	0.055 0.062	0.074 0.083	0.111 0.124
0.279		0.031 0.035	0.050 0.056	0.062 0.070	0.083 0.093	0.124 0.140
0.313		0.035 0.039	0.056 0.063	0.070 0.078	0.093 0.104	0.140 0.157
0.351		0.039 0.044	0.063 0.070	0.078 0.088	0.104 0.117	0.157 0.176
0.394	0.029 0.033	0.044 0.049	0.070 0.079	0.088 0.099	0.117 0.131	0.176 0.197
0.442	0.033 0.037	0.049 0.055	0.079 0.088	0.099 0.111	0.131 0.147	0.197 0.221
0.496	0.037 0.041	0.055 0.062	0.088 0.099	0.111 0.124	0.147 0.165	0.221 0.248
0.557	0.041 0.046	0.062 0.070	0.099 0.111	0.124 0.139	0.165 0.186	0.248 0.279
0.625	0.046 0.052	0.070 0.078	0.111 0.125	0.139 0.156	0.186 0.208	0.279 0.312
0.701	0.052 0.058	0.078 0.088	0.125 0.140	0.156 0.175	0.208 0.234	0.312 0.351
0.787	0.058 0.066	0.088 0.098	0.140 0.157	0.175 0.197	0.234 0.262	0.351 0.393
0.883	0.066 0.074	0.098 0.110	0.157 0.177	0.197 0.221	0.262 0.294	
0.991	0.074 0.083	0.110 0.124	0.177 0.198	0.221 0.248	0.294 0.330	
1.111	0.083 0.093	0.124 0.139	0.198 0.222	0.248 0.278	0.330 0.370	
1.247	0.093 0.104	0.139 0.156	0.222 0.249	0.278 0.312	0.370 0.416	
1.399	0.104 0.117	0.156 0.175	0.249 0.280	0.312 0.350		
1.570	0.117 0.131	0.175 0.196	0.280 0.314	0.350 0.392		
1.761	0.131 0.147	0.196 0.220	0.314 0.352			
1.976	0.147 0.165	0.220 0.247	0.352 0.395			
2.218	0.165 0.185	0.247 0.277				
2.488	0.185 0.207	0.277 0.311				
2.872	0.207 0.233	0.311 0.349				
3.132	0.233 0.261	0.349 0.392				
3.515	0.261 0.293					
3.943	0.293 0.329					
4.425	0.329 0.369					
4.965	0.369 0.414					

[a] The body of the table contains the bend specimen thickness (T_1) in inches.
[b] The tolerance on bend radius A is +/–0.001 in or +/–1%, whichever is the larger.
[c] F = Bend factor

Table B.2M
Bend Specimen Thickness and Bend Radius (mm)

Bend Radius, A mm[b]	Bend Specimen Thickness[a]					
	Unified Number (UNS)					
	R54520 R54810 R56320 R56400	A96061 A96063	R50400 R50550 R52400	R50250	A95083 A95086 A95456	Other
	F = 12[c]	F = 8	F = 5	F = 4	F = 3	F = 2
	≥ <	≥ <	≥ <	≥ <	≥ <	≥ <
1.78						0.79 0.89
2.01						0.89 0.99
2.24						0.99 1.12
2.51					0.74 0.84	1.12 1.27
2.82					0.84 0.94	1.27 1.42
3.18					0.94 1.07	1.42 1.57
3.56				0.79 0.89	1.07 1.19	1.57 1.78
3.99				0.89 0.99	1.19 1.32	1.78 1.98
4.47			0.79 0.89	0.99 1.12	1.32 1.50	1.98 2.24
5.03			0.89 1.02	1.12 1.24	1.50 1.68	2.24 2.51
5.64			1.02 1.12	1.24 1.40	1.68 1.88	2.51 2.82
6.32			1.12 1.27	1.40 1.57	1.88 2.11	2.82 3.15
7.09		0.79 0.89	1.27 1.42	1.57 1.78	2.11 2.36	3.15 3.56
7.95		0.89 0.99	1.42 1.60	1.78 1.98	2.36 2.64	3.56 3.99
8.92		0.99 1.12	1.60 1.78	1.98 2.24	2.64 2.97	3.99 4.47
10.01	0.74 0.84	1.12 1.24	1.78 2.01	2.24 2.51	2.97 3.33	4.47 5.00
11.23	0.84 0.94	1.24 1.40	2.01 2.24	2.51 2.82	3.33 3.73	5.00 5.61
12.60	0.94 1.04	1.40 1.57	2.24 2.51	2.82 3.15	3.73 4.19	5.61 6.30
14.15	1.04 1.17	1.57 1.78	2.51 2.82	3.15 3.53	4.19 4.72	6.30 7.09
15.88	1.17 1.32	1.78 1.98	2.82 3.18	3.53 3.96	4.72 5.28	7.09 7.92
17.01	1.32 1.47	1.98 2.24	3.18 3.56	3.96 4.45	5.28 5.94	7.92 8.92
20.00	1.47 1.68	2.24 2.49	3.56 3.99	4.45 5.00	5.94 6.65	8.92 9.98
22.43	1.68 1.88	2.49 2.79	3.99 4.50	5.00 5.61	6.65 7.47	
25.17	1.88 2.11	2.79 3.15	4.50 5.03	5.61 6.30	7.47 8.38	
28.22	2.11 2.36	3.15 3.53	5.03 5.64	6.30 7.06	8.38 9.40	
31.67	2.36 2.64	3.53 3.96	5.64 6.32	7.06 7.92	9.40 10.57	
35.53	2.64 2.97	3.96 4.45	6.32 7.11	7.92 8.89		
39.88	2.97 3.33	4.45 4.98	7.11 7.98	8.89 9.96		
44.73	3.33 3.73	4.98 5.59	7.98 8.94			
50.19	3.73 4.19	5.59 6.27	8.94 10.03			
56.34	4.19 4.70	6.27 7.04				
63.20	4.70 5.26	7.04 7.90				
72.95	5.26 5.92	7.90 8.86				
79.96	5.92 6.63	8.86 9.96				
89.28	6.63 7.44					
100.15	7.44 8.36					
112.40	8.36 9.37					
126.11	9.37 10.52					

[a] The body of the table contains the bend specimen thickness (T_1) in millimeters.
[b] The tolerance on bend radius A is ±0.03 mm or ±1%, whichever is the larger.
[c] F = Bend factor

Table B.3
Bend Specimens for Groove Welds in Tube (in)

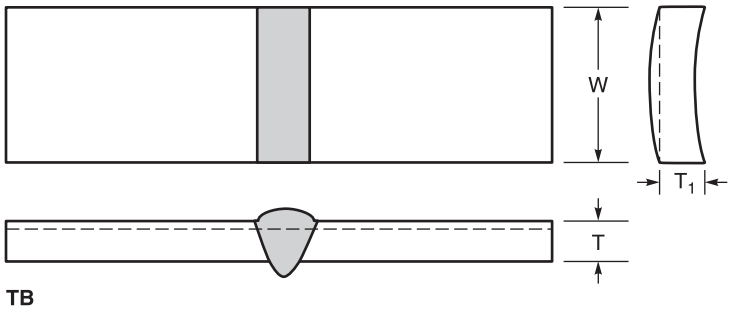
Tube			Bend Test Specimen				
Outside Diameter in	Wall Thickness T, in	Base Metal Number	Type Shown in Fig. B.1	Dimensions, in			
				T_1		W	
				Min.	Max.	Min.	Max.
< 2	All	All	Radiographic Examination Required				
2 – 5	< 0.250	All	Radiographic Examination Required				
	≥0.250 – 0.375	(Note a)	TB-e and TB-f	0.115	0.135	0.750	0.800
		All Others	TB-e and TB-f	(Note b)	(Note b)	0.750	0.800
	< 0.375 – 0.750	(Note a)	TB-e and TB-f or SB-g	0.115	0.135	0.750	0.800
				0.115	0.135	T	T
		All Others	TB-e and TB-f or SB-g	(Note c)	(Note c)	0.750	0.800
				0.350	0.400	T	T
	> 0.750	(Note a)	SB-g	0.115	0.135	T	T
		All Others	SB-g	0.350	0.400	T	T
> 5	< 0.250	All	Radiographic Inspection Required				
	≥0.250 – 0.375	(Note a)	TB-e and TB-f	0.115	0.135	1.50	1.55
		All Others	TB-e and TB-f	(Note b)	(Note b)	1.50	1.55
	> 0.375	(Note a)	TB-e and TB-f or SB-g	0.115	0.135	1.50	1.55
				0.115	0.135	T	T
	– 0.750	All Others	TB-e and TB-f or SB-g	(Note c)	(Note c)	1.50	1.55
				0.350	0.400	T	T
	> 0.750	(Note a)	SB-g	0.115	0.135	(Note d)	T
		All Others	SB-g	0.350	0.400	(Note d)	T

[a] A96061 and A96063 of Base Metal Group IV.
[b] The maximum T_1 is the thickness resulting from dressing of the curved surface to plane. The minimum T_1 is 0.9 times the maximum.
[c] The maximum T_1 is the thickness resulting from dressing the curved surface to a plane, or 0.400 in, whichever is the lesser. In the first case, the minimum T_1 is 0.9 times the maximum. In the second case, the minimum T_1 is 0.350 in.
[d] For wall thicknesses of >0.750 to 1.50 in, W is equal to T. For wall thicknesses of >1.50 in, specimens may be cut into approximately equal strips between 0.75 and 1.50 in wide for testing, or the specimens may be bent at full width.

Table B.3M
Bend Specimens for Groove Welds in Tube (mm)

Tube			Bend Test Specimen				
Outside Diameter mm	Wall Thickness T, mm	Base Metal Number	Type Shown in Fig. B.1	Dimensions, mm			
				T_1		W	
				Min.	Max.	Min.	Max.
50	All	All	Radiographic Examination Required				
50–127	< 6.4	All	Radiographic Examination Required				
	≥6.4 – 9.5	(Note a) All Others	TB-e and TB-f TB-e and TB-f	2.9 (Note b)	3.4 (Note b)	19.1 19.1	20.3 20.3
	< 9.5–19	(Note a)	TB-e and TB-f or SB-g	2.9 2.9	3.4 3.4	19. 1 T	20.3 T
		All Others	TB-e and TB-f or SB-g	(Note c) 8.9	(Note c) 10	19.1 T	20.3 T
	> 19	(Note a) All Others	SB-g SB-g	2.9 8.9	3.4 10.2	T T	T T
>127	< 6.4	All	Radiographic Examination Required				
	≥6.4–9.5	(Note a) All Others	TB-e and TB-f TB-e and TB-f	2.9 (Note b)	3.4 (Note b)	38.1 38.1	39.4 39.4
	> 9.5–19	(Note a)	TB-e and TB-f or SB-g	2.9 2.9	3.4 3.4	38.1 T	39.4 T
		All Others	TB-e and TB-f or SB-g	(Note c) 8.9	(Note c) 10.2	38.1 T	39.4 T
	> 19	(Note a) All Others	SB-g SB-g	2.9 8.9	3.4 10.2	(Note d) (Note d)	T T

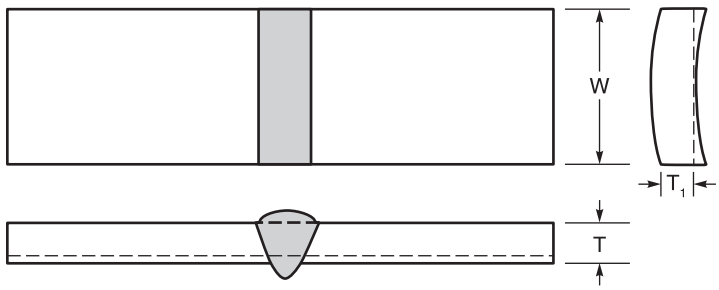
[a] A96061 and A96063 of Base Metal Group IV.
[b] The maximum T_1 is the thickness resulting from dressing of the curved surface to plane. The minimum T_1 is 0.9 times the maximum.
[c] The maximum T_1 is the thickness resulting from dressing the curved surface to a plane, or 10.16 mm, whichever is the lesser. In the first case, the minimum T_1 is 0.9 times the maximum. In the second case, the minimum T_1 is 8.89 mm.
[d] For wall thicknesses of >19.05 to 38.1 mm, W is equal to T. For wall thicknesses of >38.1 mm, specimens may be cut into approximately equal strips between 19.1 to 38.1 mm wide for testing, or the specimens may be bent at full width.



TB

NOTE: The thickness of the transverse root bend specimen is measured at the specimen edge.

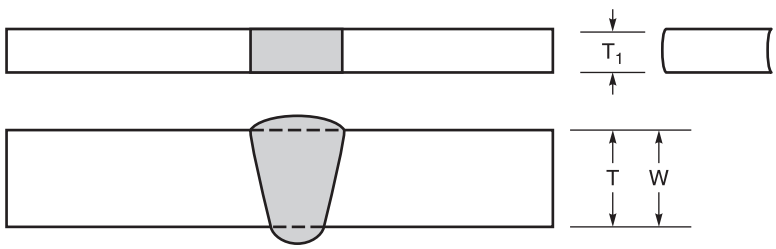
(A) TRANSVERSE ROOT BEND



TB

NOTE: The thickness of the transverse face bend specimen is measured at the specimen center.

(B) TRANSVERSE FACE BEND



SB

(C) SIDE BEND

Figure B.1—Bend Specimens in Groove Welded Tube

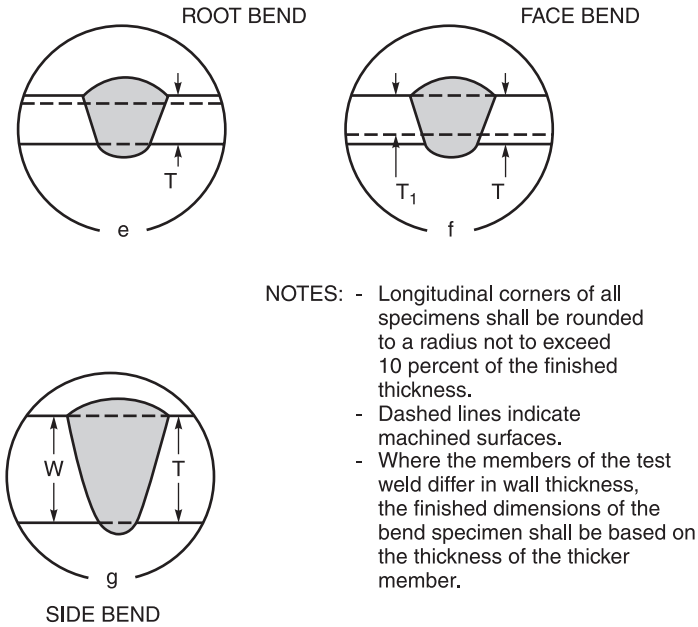

ROOT BEND
FACE BEND
T
e
T1
T
f
NOTES: - Longitudinal corners of all specimens shall be rounded to a radius not to exceed 10 percent of the finished thickness.
- Dashed lines indicate machined surfaces.
- Where the members of the test weld differ in wall thickness, the finished dimensions of the bend specimen shall be based on the thickness of the thicker member.
W
T
g
SIDE BEND
(D) BEND SPECIMEN SECTION DETAILS

Figure B.1 (Continued)—Bend Specimens in Groove Welded Tube

Annex C (Informative)
Informative References

This annex is not part of this standard but is included for informational purposes only.

American Welding Society Standards

AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes, for Shielded Metal Arc Welding*;
AWS A5.5/A5.5M, *Specification for Low Alloy Steel Electrodes for Shielded Metal Arc Welding*;
AWS A5.9/A5.9M, *Specification for Bare Stainless Steel Welding Electrodes and Rods;*
AWS A5.10/A5.10M (ISO 18273) *Welding Consumables–Wire Electrodes, Wires and Rods for Welding Of Aluminum and Aluminum-Alloys–Classification;*
AWS A5.12M/A5.12 (ISO 6848 MOD), *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting*;
AWS A5.14/A5.14M, *Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods;*
AWS A5.16/A5.16M, (ISO 24034:2010 MOD) *Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods;*
AWS A5.20/A5.20M, S*pecification for Carbon Steel Electrodes for Flux Cored Arc Welding*;
AWS A5.29/A5.29M, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*;
AWS A5.30/A5.30M, *Specification for Consumable Inserts*;
AWS A5.32M/A5.32, *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes;*
AWS B4.0M, *Standard Methods for Mechanical Testing of Welds, Metric Only*;
AWS C7.1M/C7.1, *Recommended Practices for Electron Beam Welding*;
AWS C7.2, *Recommended Practices for Laser Beam Welding, Cutting, and Allied Processes*;
AWS C7.3, *Process Specification for Electron Beam Welding*
AWS C7.4 *Process Specification and Operator Qualification for Laser Beam Welding;*
AWS D1.1/D1.1M, *Structural Welding Code — Steel*
AWS D1.2/D1.2M, *Structural Welding Code — Aluminum*
AWS D1.3/D1.3M, *Structural Welding Code — Sheet Steel*
AWS D1.4M/D1.4, *Structural Welding Code — Reinforcing Bar*
AWS D1.5/D1.5M, *Bridge Welding Code*
AWS D1.6/D1.6M, *Structural Welding Code — Stainless Steel*
AWS D3.6M, *Specification for Underwater Welding*
AWS D5.2, *Standard for Welded Steel — Elevated Tanks, Standpipes, and Reservoirs for Water Storage*, (American Waterworks Association (AWWA) Standard D100
AWS D9.1M/D9.1, *Sheet Metal Welding Code*
AWS D10.6/D10.6M, *Recommended Practices for Gas Tungsten Arc Welding Of Titanium Piping And Tubing*
AWS D14.1/D14.1M, *Industrial and Mill Crane and Other Material Handling Equipment, Specification for Welding*
AWS D14.3/D14.3M, *Specification for Welding Earthmoving, Construction, and Agricultural Equipment*
AWS D14.4/D14.4M, *Specification for Welded Joints in Machinery and Equipment*
AWS D14.5/D14.5M, *Specification for Welding of Presses and Press Components*
AWS D14.6/D14.6M, *Rotating Elements for Equipment, Specification for Welding*
AWS D14.7/D14.7M, *Recommended Practice for Surfacing and Reconditioning of Industrial Mill Rolls*
AWS D14.8M (ISO/TR 17844:2004 IDT), *Standard Methods for the Avoidance of Cold Cracks*
AWS D15.1/D15.1M, *Railroad Welding Specification for Cars and Locomotives*

AWS G2.4/G2.4M, *Guide for the Fusion Welding Of Titanium and Titanium Alloys*

American Society for Mechanical Engineers (ASME) Codes for Pressure Piping:

ASME B31.1, *Power Piping*; and
ASME B31.3, *Process Piping*.

Federal and Military Specifications, Standards, and Handbooks:

A-A–59503, *Nitrogen Technical;*
BB-O–925, *Oxygen, Technical, Gas and Liquid*;
BB-A–106, *Acetylene, Technical, Dissolved*;
BB-C–101, *Carbon Dioxide, (CO_2): Technical and U.S.P.*;
BB-H–886, *Hydrogen*;
BB-H–1168, *Helium, Technical*;
MIL-A–18455, *Argon, Technical*

Compressed Gas Association (CGA) documents:

CGA G–1.1, *Commodity Specification for Acetylene*;
CGA G–4.3, *Commodity Specification for Oxygen*;
CGA G–5.3, *Commodity Specification for Hydrogen*;
CGA G–6.2, *Commodity Specification for Carbon Dioxide*;
CGA G–9.1, *Commodity Specification for Helium*;
CGA G–10.1, *Commodity Specification for Nitrogen*; and
CGA G–11.1, *Commodity Specification for Argon*.

Society of Automotive Engineers (SAE) documents:

SAE AMS 2680, *Electron Beam Welding for Fatigue Critical Applications.*
SAE AMS 4191, *Aluminum Alloy, Welding Wire 6.3Cu – 0.30Mn – 0.18Zr – 0.15Ti – 0.10V (2319)*
SAE AMS 4951, *Titanium Welding Wire Commercially Pure Environment Controlled Packaging*
SAE AMS 4953, *Titanium Alloy Welding Wire 5Al – 2.5Sn*
SAE AMS 4956, *Titanium Alloy Welding Wire 6Al – 4V, Extra Low Interstitial Environment Controlled Packaging*
SAE AMS 5804, *Steel, Corrosion and Heat Resistant, Welding Wire, 15Cr – 25.5Ni – 1.3Mo – 2.2Ti – 0.006B – 0.30V*
SAE AMS 5805, *Steel, Corrosion and Heat Resistant, Welding Wire, 15Cr – 25.5Ni – 1.2Mo – 2.1Ti – 0.004B – 0.30V, Vacuum Induction Melted, Environment Controlled Packaging*
SAE AMS 5812, *Steel, Corrosion and Heat Resistant, Welding Wire 15Cr – 7.1Ni – 2.4Mo – 1.0Al Vacuum Induction Melted*
SAE AMS 5824, *Steel, Corrosion-Resistant, Welding Wire, 17Cr – 7.1Ni – 1.0Al*
SAE AMS 5826, *Steel, Corrosion and Heat-Resistant, Welding Wire, 15Cr – 5.1Ni – 0.30Cb(Nb) – 3.2Cu*
SAE AMS 5832, *Nickel Alloy, Corrosion and Heat Resistant, Welding Wire 52.5Ni – 19Cr – 3.0Mo – 5.1Cb(Nb) – 0.90Ti – 0.50Al – 18Fe Consumable Electrode or Vacuum Induction Melted*
SAE AMS 5837, *Nickel Alloy, Corrosion and Heat-Resistant, Welding Wire, 62Ni – 21.5Cr – 9.0Mo – 3.7Cb(Nb)*
SAE AMS 5786, *Nickel Alloy, Corrosion and Heat-Resistant, Welding Wire 62.5Ni – 5.0Cr – 24.5Mo – 5.5Fe*

Annex D (Informative)
Cross Referenced UNS numbers to [proprietary tradenames], ASTM, and AISI Designations

This annex is not part of this standard but is included for informational purposes only.

Annex D (Informative)
Material UNS numbers cross-referenced to common name, material grade or alloy type () or to proprietary trade name[ ]

Group (Table 5.4)	Materials
IB	Heat Treatable Alloy Steels: • UNS G41300 (4130), G41350 (4135), G41400 (4140), G43400 (4340), G86300 (8630), K22925 (D6AC), K44220 (300M)
IIA	Stainless Steels: Austenitic Stainless Steels: • UNS N08330 (330), S20100 (201), S20200 (202), S21900 (21–6–9), S30100 (301), S30200 (302), S30300 (303), S30400 (304) • UNS S30800 (308), S30900 (309), S31000 (310), S31600 (316), S31700 (317), S32100 (321), S34700 (347), S34800 (348) • UNS S63198 (19–9DL), S63198 (19–9DX) Ferritic Stainless Steels: • UNS S40500 (405), S40900 (409), S42900 (429), S43000 (430), S43400 (434), S43600 (436), S43035 (439), S44100 (441) • UNS S44200 (442), S44600 (446) Martensitic Stainless Steels: • UNS S40300 (403), S41000 (410), S41400 (414), S41600 (416), S42000 (420), S42200 (422), S43100 (431), S44002 (440A) • UNS S44003 (440B), S44004 (440C)
IIB	Precipitation Hardenable Stainless Steels: • UNS S13800 (PH13–8Mo), S15500 (15–5PH), S15700 (PH15–7Mo), S17400 (17–4PH), S17700 (17–7PH), S35000 (AM–350) • UNS S35500 (AM–355), S45000 [Custom®450], S45500 [Custom®455], S66286 (A–286)
IIIA	Nickel and Nickel Base Alloys: • UNS N02200 (Nickel 200), N02201 (Nickel 201), N04400 [Monel® 400], N06002 [Hastelloy®X], N06007 [Hastelloy®G] • UNSN06455 [Hastelloy® C4], N06600 [Inconel® 600], N06625 [Inconel® 625], N06975 [Hastelloy® G2] • UNS N08020 [Carpenter® 20Cb3], N08320 [Haynes® 20 Mod.], N08800 [Incoloy® 800], N08810 [Incoloy® 800H] • UNS N08825 [Incoloy® 825], N10001 [Hastelloy® B], N10002 [Hastelloy® C], N10003 [Hastelloy® N] • UNS N10276 [Hastelloy® C–276], N10665 [Hastelloy® B2]

IIIB	Precipitation Hardening Nickel and Nickel Base Alloys: • UNS N05500 [Monel® K500], N06601 [Inconel® 601], N07041 [Rene® 41], N07718 [Inconel® 718], N07750 [Inconel® X750] • UNS N09706 [Inconel® 706], N09901 [Incoloy® 901] • UNS N19903 [Incoloy® 903], N19907 [Incoloy® 907], N19909 [Incoloy® 909]
IV	Non Heat Treatable Aluminum Alloys: • UNS A91060 (1060), A91100 (1100), A93003 (3003), A93004 (3004), A95052 (5052), A95083 (5083), A95086 (5086) • UNS A95154 (5154), A95254 (5254), A95454 (5454), A95456 (5456), A95652 (5652) Heat Treatable Aluminum Alloys: • UNS A03550 (355), A03560 (356), A03570 (357), A92014 (2014), A92219 (2219), A96061 (6061), A96063 (6063)
V	Magnesium Alloys: • UNS M10100 (AM100A), M11311 (AZ31B), M11610 (AZ61A), M11800 (AZ80A), M11910 (AZ91A), M11920 (AZ92A) • UNS M12330 (EZ33A), M13210 (HM21A), M13310 (HK31A), M13312 (HM31A), M13320 (HZ32A), M14141 (LA141A) • UNS M16620 (ZH62A), M18220 (QE22A)
VI	Titanium Alloys: • CP Titanium UNS R50250 (25), UNS R50400 (40), UNS R50550 (55) • UNS R54520 (Ti–5AL–2.5Sn), R54620 (Ti–6Al–2Sn–4Zr–2Mo), R54810 (Ti–8Al–1Mo–1V), R56210 (Ti–6Al–2Cb–1Ta–1Mo) • UNS R56260 (Ti–6Al–2Sn–4Zr–6Mo), R56320 (Ti–3Al–2.5V), R56400 (Ti–6Al–4V), R56620 (Ti–6Al–6V–2Sn) • UNS R58640 (Ti–3Al–8V–6Cr–4Mo–4Zr)
VII	Cobalt Base Alloys: • UNS R30006 [Stellite® 6], R30106 [Stellite® 6], R30021[Stellite® 21], R30023 [Stellite® 23] • UNS R30027 [Stellite® 27], R30030 [Stellite® 30], R30031 [Stellite® 31] • UNS R30188 [Haynes® 188], R30605[Carpenter® L–605], R30816 [S–816]

Annex E (Informative)
Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard, but is included for informational purposes only.

E1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

E2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

E3 General Procedure for all Requests

E3.1 Submission. All requests shall be sent to the Managing Director of AWS Standards Development Division. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

E3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

E3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

E3.4 Questions(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

E3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

E3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

E4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

E5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

E6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

Annex F (Informative)
Commentary

This annex is not part of this standard, but is included for informational purposes only.

Foreword

Note: All references to numbered paragraphs, tables and figures, unless otherwise indicated, refer to subclauses, tables, or figures in AWS D17.1/D17.1M:2017, *Specification for Fusion Welding for Aerospace Applications*. Reference to subclauses, tables, or figures in this commentary is prefixed with the letter F. For example, Figure 5.1 is in AWS D17.1/D17.1M, while Clause F5.2 is in this commentary.

This commentary on AWS D17.1/D17.1M:2017 has been prepared to generate better understanding in the application of this specification in aircraft and aerospace welding.

Since the specification cannot contain background information or discuss the committee's intent, it is the function of this commentary to fill this need.

Suggestions for application, as well as clarification of specification requirements, are offered with specific emphasis on requirements that differ from the requirements given in MIL-STD–1595, or MIL-STD–2219.

It should be recognized that the fundamental premise of this specification is to provide general stipulations and to leave sufficient latitude for the exercise of engineering judgment. Due to the diverse nature of the Aerospace industry, it is not possible to establish a single set of specification controls that are applicable to all design applications. This specification represents the collective experience of the committee, and while some provisions may seem overly conservative for some applications, they may be too liberal in others. All provisions are based on sound engineering practice. The Engineering Authority assumes responsibility for applying this specification in a given design situation and modifying the requirements to achieve the desired performance at reasonable cost without taking undue risk.

The committee, therefore, believes that a commentary is the most suitable means to provide clarification as well as proper interpretation of the many specification requirements. Obviously, the size of the commentary imposes restrictions on the extent of coverage on a given requirement.

This commentary is not intended to provide a historical background of the development of this specification, nor is it intended to provide a detailed resume of the studies and research data reviewed by the committee in formulating the provisions of this specification.

This specification does not treat the selection of materials or the sizing of the weld joints. Such considerations are assumed to be covered elsewhere; that is the statement of work, corporate design manuals, etc.

The committee has endeavored to produce a useful document suitable in language, form, and coverage for welding in the Aerospace and Aircraft industry. The specification provides a means for establishing welding standards for use in the design and construction by the customer or the Engineering Authority. The specification includes provisions for the regulation of welding that are necessary for public safety.

The committee recommends that the customer or the Engineering Authority be guided by this commentary in application of the specification to the welded structure. The commentary is not intended to supplement code requirements, but only to provide a useful document for interpretation and application of the specification; none of its provisions are binding.

It is the intention of the Committee on Welding in the Aircraft and Aerospace Industries to revise the commentary on a regular basis so that commentary on changes to the specification can be promptly supplied to the user. In this manner, the commentary will always be current with the edition of the specification for fusion welding Aerospace structures with which it is bound.

F1. General Requirements

F1.1 Scope

This specification provides general welding requirements applicable to aerospace welded structures. It replaces MIL-STD–2219, *Fusion Welding for Aerospace Applications*, and MIL-STD–1595, *Qualification of Aircraft Missile and Aerospace Fusion Welders*, and is intended to complement any specification for the design and construction of aerospace and aircraft structures. When using this specification, customers and the Engineering Authority should recognize that not all provisions may be applicable or suitable to their particular structure.

Because of the diversity of the mission and systems criteria for aerospace structures, the specification committee allows modification of the provisions when deemed necessary by the Engineering Authority and when supported by engineering data. All modification of specification provisions should be clearly referenced in the contractual agreement between the customer and the Engineering Authority.

F1.1.1. Flight Hardware. In the United States, nonmilitary flight structures, including engines, used for commercial and general aviation are subject to the requirements set forth in the Code of Federal Regulations (CFR), Title 14. The parts of the CFR most directly applicable to D17.1/D17.1M are Parts 23, 25, 27, 29, 33, and 43.

F1.1.2 Nonflight Hardware. Contract requirements in the aerospace industry may not distinguish between welding intended for flight hardware (engines, structures, and flight systems) and welding for support functions (nonflight systems, tooling, ground support equipment, and related nonconventional facilities). For this reason it was necessary to create Clause 9.

F1.2 Units of Measure. For historical purposes, the units of measure have been standardized on the U.S. Customary Units, with close equivalents in International System Units. The engineering documentation units should drive which measurement units are used during welding and inspection.

F1.3 Safety. This specification cannot address all the safety and health regulations that apply to welding in every region where welding may occur. Therefore, some reference information is provided for the users to review for a better understanding of the risks of using these processes. But, users need to review and comply with the health and safety regulations that apply to the region they are in. Some companies will institute more stringent requirements above local health and safety regulations.

F1.4 Classification. Aircraft and aerospace structures are classified according to structural integrity requirements, and welds in these structures commonly are subject to the same classifications. However, when design analysis can demonstrate that the weld(s), or a portion of the weld(s) in the structure is/are not subject to the same structural integrity requirements or loads as the rest of the structure, these welds may carry different classifications.

MIL-STD–2219 provided the following nonmandatory clarification for the use of weld classifications A, B, and C:

Class A: Critical applications. Welds the single failure of which would cause loss of system, loss of major component, loss of control, unintentional release of critical stores, or inability to release armament stores, or endangering personnel.

Class B: Semicritical application. Welds where a failure would reduce overall efficiency of the system, preclude the intended function or use of the equipment; but loss of the system or endangering of personnel would not be experienced.

Class C: Noncritical application. Welds where a failure would not affect the efficiency of the system or endanger personnel.

In general, much of the weld design data for Class A and Class B welds used in the aircraft and aerospace industry was derived from statistical analysis of data derived from test welds, and studies of weld defects. The extent of the testing may not be consistent from base metal/filler metal combination to base metal/base metal combination or gauge to gauge. Early industry databases generated in the 1950s and 1960s established acceptance standards that were related to workmanship standards and did not reflect the fracture toughness characteristics of the various material/filler metal combinations.

Consequently, there may be a degree of conservatism in the application of acceptance standards to welds in certain materials, while in others the standards may be too liberal. When selecting the appropriate weld classification and the extent of inspection, the Engineering Authority should consider not only the structural integrity requirements, but the ability to inspect, repair, or replace during the design life of the structures.

This specification recognizes that there are other factors that may enter into the selection of weld classifications and consequently uses weld classifications to identify the level for inspection and the acceptance criteria. The reason for this approach is that two identical welds may be exposed to different environments, have different degrees of accessibility for maintenance inspection during its design life, and be subject to different loading conditions (i.e., static versus dynamic). It is incumbent on the Engineering Authority to establish the weld classification that is both cost effective and ensures the structural integrity of the weldment for any given application.

F2. Normative References

Government standards organizations and industry standards organizations maintain their standards to be in line with current practices, technology and regulatory requirements. Expect that there will be periodic changes to reference standards. It is important to clearly understand the effective edition of any given reference standard. In the case of undated references, the contract or purchase order can explicitly define the effective date, which then controls the edition. When explicitly defined, it is typically the edition of the reference in effect at the date of the contract or purchase order rather than the latest edition in effect at the time of fabrication.

In some situations, the latest edition of a standard in effect may be a cancellation notice or a supersession notice. The text within a supersession notice provides clear direction on the replacement standard to use. Carefully review the text within a cancellation notice to determine whether there is mandatory direction on the required replacement provisions. In the absence of mandatory direction, consult with the Engineering Authority to determine suitable replacement provisions.

F3. Terms and Definitions

The purpose of the Terms and Definitions clause is to define terms that are unique to the aircraft and aerospace industry or may have a meaning different than in other fabrication industries.

F4. Design of Welded Connections

F4.1 Scope. The ability of a weld to achieve its purpose or mission starts with the design process. Neither fabrication prowess nor inspection detection capability can overcome a poor or inadequate design. The design process, in a large part, will set the baseline for fabrication and life costs of the weldment. Weld joint selection and joint location play a major role in a weld's manufacturability and inspectability. Joint accessibility for both welding and inspection provide a good basis for a sound weld. It is important that the design process consider fabrication and inspection techniques necessary to produce an acceptable weld.

F4.2 Weldment Design Data. The first step in the design process should be to ensure that there is adequate data that reflect the performance of the weld zone under the anticipated loading conditions. This weld zone includes the weld metal and the adjacent parent metal, or heat-affected zone (HAZ). All of the components of the weld zone, not just the weld metal, make up the weld joint.

The weld joint performance and properties are often affected by subsequent processing. This processing includes heat treatment, forming, or peening, to name a few. Consideration of weld discontinuities is a part of sound design analysis. It is important to remember that fusion welding is an in-situ casting process and weld metal discontinuities often occur.

The presence or absence of weld reinforcement, or the use of weld lands, determines which area of the weld zone drives performance: the weld, the HAZ, or parent metal. Weld lands are sometimes used where the joint strength, or other properties, are less than the parent metal.

Shrinkage and the resulting residual stress are normal occurrences in fusion welding. The residual stress present will affect the performance of the weld zone. Under some loading conditions this effect will be deleterious. Steps may be

necessary to either reduce the residual stress in the weld zone with a postwelding treatment or to compensate for its effects by modifying the weld joint design. In the case of shrinkage, prewelding joint details may include added material to allow the weldment to meet postwelding dimensional requirements.

F4.3 General Drawing Requirements

F4.3.1 Drawing Information. There should be sufficient unambiguous information concerning the size, extent, type, location, and inspection requirements for the welds on the engineering drawing to allow the fabricator to produce the welds. The engineering drawing is often the sole mechanism by which the Engineering Authority communicates the weldment requirements to the fabricator and the inspector. There are some cases where the standard symbols of AWS A2.4 do not adequately describe the required weld and inspections. In these cases the Engineering Authority should add enough additional information, often in the form of weld details, to the engineering drawing to provide reasonable assurance that the fabricator understands what type of weld to produce and how to inspect it.

F4.3.2 Groove Welds. Full penetration groove welds are the default requirement. Full penetration welds do not have the built-in weld root discontinuity that is always present in a partial penetration weld joint. Thus, the internal examination of full penetration groove welds for discontinuities is more straightforward than that for partial penetration groove welds. The effective area of a groove weld coupled with the weld metal strength indicates the load-carrying capacity of the weld metal. Weld reinforcement is not considered when calculating the effective area of a groove weld for loading analysis because reinforcement is of little benefit to the load-carrying capacity of the weld joint.

F4.3.3 Fillet Welds. The typical practice in welding is to specify the fillet weld size as a minimum with the maximum size controlled by the governing fabrication specification. However, stating a specific maximum weld size is prudent when mechanical interference may occur at a higher assembly level. The effective area of a fillet weld coupled with the strength of the weld filler metal in shear determines the strength of the fillet joint. Some fillet weld metals may have shear strength values that differ according to the direction of the applied shear stress. The principal shear stress directions are parallel or perpendicular (longitudinal or transverse) to the length of the fillet weld.

In this specification the minimum distance from the design joint root to the face of the triangle representative of the fillet weld cross section for the minimum allowable size is the effective throat. The definition here is consistent with that in AWS D1.1/D1.1M but differs from AWS A3.0M/A3.0. Because fillet welds are triangular in cross section (often a right triangle), increasing the effective throat requires a disproportionate amount of additional weld metal. For example, changing the fillet weld size from 1/8 to 3/16 in [3.2 to 4.8 mm] in a 90-degree equal leg fillet weld with no root gap increases the effective throat by a factor of 1.5 while weld metal volume increases by a factor of 2.25. This modest joint strength boost comes with a proportionally larger potential for distortion.

F4.3.4 Essential Information. The eight listed categories provide the minimum drawing information sufficient to address most situations. It is incumbent upon the Engineering Authority to add additional requirements to the engineering documentation when warranted. The Engineering Authority has met its obligations when all essential information required to successfully perform the weld has been unambiguously documented.

F4.3.5 Inspection Requirements. It is important to establish both the appropriate inspections and acceptance criteria for each weld joint or separate regions within the weld joint, based upon the service loading conditions. The weld joint classifications A, B, and C provide generally suitable levels of inspection and acceptance criteria. The Engineering Authority may tailor inspection and acceptance criteria for each weld to best suit the application and the loading conditions.

Inspections and acceptance criteria applied generically to a weldment may lead to under-inspection of some welds and over-inspection of others. Consider the practicality of meeting the acceptance criteria chosen. Choosing acceptance criteria beyond the capability of the welding process may lead to numerous inspection rejections, increasing costs. Every inspection technique has its own weld joint access requirements and detection limitations. Designs and/or the inspection process(es) selected may require reevaluation if the acceptance criteria are beyond the detection capability of the inspection process(es).

F5. Welding Procedure and Performance Qualification

The fundamental purpose of the welding procedure and performance qualification clause of this specification is to provide basic requirements applicable to most situations. When necessary, it allows latitude for the use of Engineering Authority's judgment.

This version of D17.1/D17.1M:2017 has made significant changes to this section. In previous revisions, the main focus was performance qualification of welding personnel with much of the procedure qualification left to the Engineering Authority to specify. Currently, the subcommittee's intent is to specify the exact requirements for procedure qualification, which the Engineering Authority can use as is or make additions or exceptions to as necessary.

F5.1 General. As a reminder, MIL-STD–1595A and MIL-STD–2219 were used as the basis for this clause. It continues to evolve with each revision.

F5.2 Welding Procedure Data and Qualification. All welds require a written procedure. The required content of the WPS has been specified in Table 5.1. As stated in 5.2.2, "WPSs for Class A and B welds shall have a supporting PQR". In other words, procedures for those welds will be qualified with data proving the ability to meet the requirements. WPSs for Class C welds do not require qualification data. Suggested format for WPSs and PQRs is in Annex G.

D17.1/D17.1M:2017, as referenced above, has not waived the need for qualification of Class A and Class B welds. However, the requirement for settings on manual welds is not practical. The welder is unable to view amperage or voltage meter readings, or to accurately estimate travel speed. Aerospace and Aircraft welder qualification/certification requirements often exceed structural welding qualification requirements. Consequently, the committee has moved beyond the old paradigm of specifying weld settings on manual operations. Other methods have been defined and used to capture and maintain the necessary control. One method, when welding with GTAW, is to specify a single tungsten electrode size, electrode tip preparation geometry, and shielding gas setting. This results in a more practical and measurable method for controlling the amperage rather than having to specify a specific amperage level. A certified welder is trained to recognize weld puddle behavior.

The weld variability can be reduced by qualifying the qualification variables in a written weld procedure such as: type of gas, AC or DC current, polarity, tungsten geometry, base metal alloy (and condition), filler type and diameter, torch size, cup size, lead/lag angle, appropriate fixturing, joint backup gas or other, shielding trailers, gas flow and most important "specifics'' for successful welding of the given component. The basic rule is if the welder can control a welding variable during the welding process (Hood Up), such as those listed above, they are to be specified/qualified on the weld procedure specification/weld schedule and locked down to specific parameters. Welding variables that cannot be controlled by the welder when welding (Hood Down) need not be listed on the weld procedure.

F.5.3 & F.5.4 Performance Qualification. In this revision, little has changed for welder and welding operator performance qualification requirements. The changes are primarily editorial.

F6. Fabrication

F6.1 Scope. The fundamental purpose of the Fabrication clause of this specification is to provide basic requirements applicable to most situations. When necessary, it allows latitude for use of the engineering judgment by the Engineering Authority.

F6.2 Welding Consumables. Due to the criticality of many aerospace weldments, the identification, storage, and the use of all welding consumables (including wires, rods, inserts, fluxes, gases, etc.) require proper controls. Many failures have been attributed to using the incorrect material during welding. The intent of this section is to provide the minimum controls necessary to control all consumables.

F6.3 Welding Equipment. A certain minimum amount of maintenance, possibly including periodic calibrations, is necessary to prevent equipment-related weld defects. Calibration should also be performed when there is reason to question the capability of the machine to produce acceptable welds.

F6.4 Weld Settings. The committee has written the specification with the intent that weld settings from the qualified WPS are used during the production welding to maintain maximum repeatability. For manual welding, the qualified WPS will generally not list those parameters that are not fixed prior to the start of welding. These parameters vary with process but may include arc voltage, current, and travel speed.

After a major repair of mechanized or automatic welding equipment, it is important to prepare and test the reproducibility test weld to ensure proper operation of the equipment. Reproducibility test weld should also be used to determine and remedy continual quality problems in the weld shop.

F6.5 Preweld Cleaning and Other Preparation. Before welding the joint surfaces should be properly cleaned, (chemically and/or mechanically) and then protected from contamination. This preparation procedure should be documented and consistently followed.

F6.6 Preweld Joint Preparation and Fitup. Proper joint preparations and adhering to fitup gap requirements will reduce or eliminate problems associated with weld penetration, distortion, and mismatch.

F6.7 Preheating and Interpass Temperature Control. Although Table 6.3 provides recommended preheat and interpass temperatures for certain materials, it is the fabricator's responsibility to establish these temperatures. The fabricator, at minimum, should consider the material's chemical composition, metallurgical properties, and the part's integrity requirement during the establishment of the preheat and the interpass temperature controls. Preheat and interpass temperature listed on the qualified WPS must be used and maintained during production welding.

F6.8 Tack Welds. Qualification variables, including filler material, should be specified in the WPS. Experience has proved the need to either fully consume the tack weld in the next weld pass or remove the tack welds before next weld pass. It is important to be aware of fitup requirements prior to tacking as well as preheat requirements as documented on the WPS.

F6.9 Weld Start and Run-Off Tabs. Many common start/stop defects can be eliminated from the welded joint by the use of tabs. It is important that tabs be of the same material as the base metal because of the mixing of the metals in the weld pool.

F6.10 Weld Shielding for GTAW, GMAW, and PAW. The weld and heat-affected zone should be shielded during the welding process to prevent defects caused by oxidation. Reactive base metal, such as titanium and its alloys, requires special attention in shielding. In such materials, deposited and solidified weld metal immediately behind and a certain distance beyond the progressing weld pool must also be shielded to preclude contamination. AWS G2.4 provides guidelines for the shielding of titanium and its alloys. The consumables, such as shielding gases, fluxes, etc., should always be listed in the WPS.

F6.11 Tungsten Electrodes. AWS A5.12M/A5.12, *Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting*, is the industry standard for tungsten electrodes used in GTAW and PAW.

F6.12 Filler Materials. Filler materials change the metallurgy of the weld. In some cases it can be used to increase the weldability of a material or provide additional strength. Therefore, it is always incumbent on the Engineering Authority to choose the filler material for the property sought. For guidance, Tables 6.4, 6.5, and 6.6 provide filler materials normally used in welding aerospace base materials.

F6.13 Interpass Cleaning. Interpass cleaning in a multipass weld is important in obtaining a weld with acceptable quality. This will remove contaminants, such as oxides and slag, deposited on the weld bead or joint surface during previous weld pass(es). Chemical or liquid solutions are not recommended because of the difficulty of their removal. Cleaning of titanium weldments is not performed until after inspection to verify that the weld does not contain oxygen contamination.

F6.17 Weld Identification Requirements. The intent is that weldments will have traceability to their welder. A structurally critical weld, defined as such by the Engineering Authority, will typically have traceability and processing history that is documented and maintained through the life of the product. Typically, the fabricator is responsible for maintaining all traceability and processing documentation for a period defined by the Engineering Authority or a contract document.

F6.20 Repair. This activity takes place on the rejected part dispositioned by the Engineering Authority for a repair.

Usually, the Engineering Authority dispositions a rejected part for a repair when it is deemed possible to correct and bring the weld or the part within the specified acceptance, integrity, and/or functional requirement. All operations involved in this activity are a part of the disposition from the Engineering Authority. The fabricator and the welder must follow provided directions.

Some examples of the disposition to repair a rejected part include, but are not limited to:

(1) welding from the root side to correct incomplete penetration,

(2) welding on a heat-treated part,

(3) additional weld on the part to bring the part within the dimensional or the configuration requirement of the drawing,

(4) welding to correct an unintentional gouge or a nick,

(5) weld was made using filler metal other than that specified by the Engineering Authority

F7. Inspection

F7.1 Qualification of NDE Personnel. Clause 7.1.2 now provides clear requirements for the qualification of visual weld inspectors. Certification of visual weld inspectors can now be per one of three methods: AWS QC1; or by a certification program approved by the Engineering Authority; or by a certification program approved by the fabricator's quality organization management. If the fabricator's quality organization management approval program is used, it must be based on experience, training, and testing criteria cited in AWS B5.2.

Clause 7.1.3 contains requirements for near vision and color perception tests administered to the visual weld inspector. These tests could now be any that is selected by the test administrator. It has removed the use of Jaeger J1 at 12 in [300 mm] and Jaeger J2 at 16 in [405 mm], a requirement that was in AWS D17.1/D17.1M:2010. It now allows use of Snellen and tumbling E chart, or any other world language letter, or any character or symbol as deemed appropriate by the personnel administrating the test. This change now recognizes various areas of the world where English may not be the primary language of the communication.

F7.2 Visual Weld Inspection. Clause 7.2 in this revision has the requirement to inspect all welds visually the same as was in Clause 7.3 of AWS D17.1/D17.1M:2010. All welds should be visually inspected prior to subjecting them to other NDE examination. Visual inspection should be for any surface defect easily discernible and acceptable or rejectable using measurement tools (gauges and scales) as specified in Table 7.1 by the visual weld inspector (e.g. lack of penetration, crack, weld reinforcement, fillet weld sizes, discoloration, and any other within Table 7.1). This clause, however, does not explicitly require the visual inspection of inaccessible root surfaces. It is important for Engineering to recognize when the root side of the weld may not be accessible for visual inspection, and, if necessary, specify supplemental inspections such as borescopy or radiography to verify the root side quality.

Requirements for inspection using penetrant, magnetic particle, and radiographic examination methods are the same as those in AWS D17.1/D17.1M:2010. Requirements for inspection using ultrasonic inspection have changed over that in AWS D17.1/D17.1M:2010. G7.2.1 through G7.2.6 provide further guidance on the use of each particular NDE method and associated requirements in Table 7.1.

F7.3.1 Penetrant Testing (PT). All Class A and B welds in nonferromagnetic materials (e.g. aluminum, titanium, austenitic steels, copper) are required by this specification to be penetrant tested. This inspection method only detects flaws open to the surface and not to the subsurface. All defects detected by penetrant technique are required to be evaluated and accepted or rejected on the basis of requirement in Table 7.1.

Class A or B welds in ferromagnetic materials (e.g. carbon and alloy steels, martensitic and duplex stainless steels, and most PH stainless steels) are not required to be subjected to penetrant testing unless so required on the engineering drawing or by the Engineering Authority. When the engineering requires inspection of ferromagnetic materials using penetrant testing, all defects detected by penetrant technique are required to be evaluated and accepted or rejected on the basis of requirement in Table 7.1.

Similar to visual weld inspection, penetrant testing of inaccessible weld root side surface is not explicitly required unless the requirement is specified by the Engineering Authority. In lieu of inspecting such inaccessible surfaces by penetrant testing method, use any other method deemed appropriate by the Engineering Authority. It is important to get this waiver or approval when particular root surface is considered inaccessible by the fabricator prior to inspection initiation.

If for any reason, weld surfaces are ground, penetrant specifications require those surfaces to be prepenetrant etched prior to subjecting the surface to penetrant testing methods. However, it is important to keep in mind that etching solutions, when trapped and remained or dried up (especially on root side of weld) without complete removal, can result in initiation and propagation of corrosion pits and stress corrosion cracking. It is important for the fabricator to reach an agreement with the Engineering Authority when to omit such prepenetrant etching operations for a particular weldment.

Type I penetrant removable by any method and sensitivity level 2 or better is required to be used in penetrant testing. It is important to understand requirements in NDE inspection documents specified on engineering or other aerospace

documents such as Department of Defense documents (e.g. NDE Manual TO 33-B1.1). Engineering specified or other documents may prohibit use of particular types of penetrant materials (e.g. water washable penetrants).

F7.3.2 Magnetic Particle Testing (MT). All Class A and B welds in ferromagnetic materials (e.g. carbon and alloy steels, martensitic and duplex stainless steels, and most PH stainless steels) are required by this specification to be magnetic particle tested.

This inspection method is primarily used to detect defects open to surface.

Discontinuities detected by particle testing are required to be evaluated and accepted or rejected on the basis of requirement in Table 7.1.

Similar to visual weld inspection, penetrant examination of inaccessible weld root side surface is not explicitly required unless the requirement is specified by the Engineering Authority.

F7.3.3 Radiographic Testing (RT). All Class A welds are required by this specification to be radiographically tested.

This inspection method detects volumetric defects. The limitation of this method of examination is the size of the defect in relation to the thickness of the material being inspected. All defects detected by radiographic testing are to be evaluated and accepted or rejected on the basis of requirement for subsurface flaws in Table 7.1, which is the reason that surface examination techniques are performed by methods other than radiographic examination.

Ensure that a written procedure that includes a technique data sheet is developed based on the part geometry as specified in ASTM E1742 and used during inspection of the part.

Class B and Class C welds are not required to be radiographically tested unless specifically required by engineering. When engineering does not require radiographic testing of Class B and Class C welds, neither subsurface (volume between face and root surface) flaw/defect criteria specified in Table 7.1 apply.

Digital detector array (DDA), or sometimes referred to as digital radiography, should be used when so approved as an alternate to ASTM E1742 or as directed by the Engineering Authority.

F7.3.4 Ultrasonic Testing (UT). Ultrasonic testing may be used as an alternate to radiographic testing. It is performed only when specified on drawing, contract, or by the Engineering Authority. The default specification for ultrasonic testing is ASTM E164.

Since the ultrasonic examination technique is in lieu of or alternate to radiographic examination, it should be used to detect defects lying below the surface. All subsurface defects detected by ultrasonic technique are required to be evaluated and accepted or rejected on the basis of requirement for subsurface flaws in Table 7.1.

Class B and Class C welds are not required to be ultrasonically tested, similar to radiographic testing, unless specifically required by engineering. When engineering does not require ultrasonic testing of Class B and Class C welds, neither subsurface (volume between face and root surface) flaw/defect criteria specified in Table 7.1 apply.

F7.3.5 Proof Testing (PRT). Proof testing is performed when specified on drawing or contract, or when required by Engineering Authority. In such cases, a proof test should not commence until all required specimen configurations, test methods and procedures, and acceptance criteria are received from the Engineering Authority.

F7.4 Acceptance Criteria.

Requirement of Table 7.1. Table 7.1 has been revised so that inspectors have one single location for acceptance criteria. Subsurface requirements in Table 7.1 are only applicable when radiographic (see requirement in 7.3.3) or ultrasonic examination (see requirement in 7.3.4) has been specified.

F8. Repair of Existing Structures

F8.1 Scope. The purpose behind the clause on repair welding is to establish a consistent systems approach for in-service weld repairs to aviation flight hardware. This will include all primary and secondary structures and component repairs. This systems approach will follow the general format of the main and subclauses of D17.1/D17.1M for application of a welding repair. In general, there are weld repairs to in-service components performed every day at repair stations or other FAA-approved facilities and this clause of the welding specification may or may not apply to those repairs. The decision

to apply this clause resides with the Engineering Authority and the governmental regulating agency, as permitted by the Code of Federal Regulations (Title 14, Parts 43 and 145). The final authority for all approvals for weld repair procedures resides solely with the governmental regulating agency.

Note: When the weld repair becomes an integral part of flight hardware maintenance, Clause 8 will apply.

Generally, an overhaul manual approved by the governmental regulating agency will contain established weld repair procedures that are acknowledged and approved by the FAA for use by Repair Stations or the OEMs as permitted, without additional qualification or re-qualification of which are used for generic or common weld repairs. That distinction is limited for weld repairs to fight hardware on structures which have limited or unsatisfactory weldability, such as Aluminum Alloy 7075-T73. As corrosion and fatigue begin to affect the base metal in critical areas, the Engineering Authority will need to investigate and develop economical means to repair welding. This will prompt the welding industry to develop new uses for current and future technologies.

F8.2 Design. Stress analyses performed to satisfy design requirements could vary from performing qualitative engineering assessment of loading to a detailed finite element analysis of the repaired area.

F8.3 Welding Procedures. Originally, most weld procedures may not have been qualified or have had an adequately documented weld procedure. Where welds become an integral method of fabrication, the need and requirement for developing and documenting the weld procedure becomes an important aspect of weld repairs.

This clause of the specification prohibits the weld repair application unless sufficient testing has been performed. The testing of the weld repair procedure must satisfactorily apply to the specific application. This will include weld repair procedures that may have been previously qualified for another application or base metal/weld metal combination. If sufficient data exists to support another similar application, the Engineering Authority may approve the weld repair procedure for additional uses.

The actual application of the weld repair procedure must be the controlling factor when following previously qualified weld procedures.

F8.4 Welder and Welding Operator Qualification. For qualification of personnel to perform repair welding on existing hardware, the same requirements are applied that would be used to build new hardware. The same ability is necessary to obtain acceptable welds.

F8.6 Weld Repair Inspection. In most cases, the currently specified inspection methods are adequate for weld repairs. When the inspection is not normally used for the item because of limitations of the method, the Engineering Authority may authorize alternative inspection methods if the current method is not sufficient. Approval from the appropriate government agency is required. Each weld repair in areas not normally inspected should have adequate Engineering oversight, ensuring the adequacy of the repair inspection.

F8.7 Grounding and Bonding. Welding on aircraft poses additional risks to other hardware. With the complex electronics and moving parts on the vehicle, the Engineering Authority needs to verify that there will not be damage to these other components from the electrical path to workpiece lead.

F8.8 Repair Documentation. The use of welding to repair items that are not normally welded is a very possible situation and the need to document the location of the weld repair is critical to track and monitor the repair in the event of failure. Weld repairs performed per this clause have inherent liability issues and documentation of the repair is important to provide a long-term record of the suggested welding variables listed in this clause. The variables listed in Clause 8 are not all inclusive and may be changed by adding or deleting some of the welding variables depending on the welding procedure development. The documentation provides feedback to the extent the weld repair was utilized and any corresponding corrective action taken is properly documented.

F9. Nonflight Hardware

This specification recognizes fundamental differences between welding flight and nonflight structures (which are often overlooked in contracts), and allows for their unique requirements to be covered by a single master specification.

F9.1 Scope. The typical aerospace hardware considered herein support the operations of manufacturing, transporting, receiving, handling, assembly, inspection, test, checkout, and service of aircraft, missile and space vehicles and payloads, and the launching of small or ballistic missiles, space vehicles, and payloads.

F9.2 Exceptions and Additional Requirements. This clause is intended to establish uniform practices for the design, qualification, fabrication, and inspection of nonflight hardware. This goal is accomplished by combining the requirements of consensus industrial welding codes with supplementary requirements as necessary. Supplementary requirements were added in areas where the pertinent industrial code either contained no requirements or contained requirements insufficient for aerospace applications. This approach is consistent with the intended use of the referenced codes which typically establish minimum requirements. For example, even though AWS D1.1/D1.1M, *Structural Welding Code — Steel*, contains requirements for NDE methods and acceptance criteria, NDE is not required unless specifically requested in the contract agreement (such a request would be separate from the general AWS D1.1/D1.1M callout and would have to contain details on the desired methods and extent of examination). A normative annex in AWS D1.1/D1.1M contains examples of how to write a specification that invokes some of the optional provisions of that code. ASME B31.3*, Code for Pressure Piping — Process Piping,* states that *"The owner is also responsible for imposing requirements supplementary to those of the code if necessary to assure safe piping for the proposed installation.*" Some additional examples of the supplementary requirements are the following:

(1) data requirements for engineering drawings;

(2) requirements for material certifications;

(3) requirements for structural welding of nontraditional structural alloys;

(4) provisions for verification of WPS and welder qualifications;

(5) fabrication techniques, including preheating and postweld heating requirements;

(6) requirements for visual inspection and NDE (including personnel qualification, methods, extent, and acceptance criteria) as well as rework.

Excluded from the requirements of Clause 9 are pressure vessels for nonflight applications which should be fabricated in accordance with the ASME *Boiler and Pressure Vessel Code* (BPVC). Supplementary requirements are not added to the ASME BPVC due to the fact that the BPVC directly links weld design factors (e.g., joint efficiencies and allowable stresses) to the type and extent of NDE performed, and also establishes extensive requirements for such subjects as weld categories, weld types, service restrictions, and fabrication details (including detailed requirements for postweld heat treatment). Furthermore, the ASME BPVC states that engineering judgment used in the application of the BPVC ". . . must never be used to overrule mandatory requirements or specific provisions of the Code."

Annex G (Informative)
Samples of Welding Forms for WPSs, PQRs, and Welder Performance Qualifications

This annex is not part of this standard but is included for informational purposes only.

SAMPLE WELDING PROCEDURE SPECIFICATION (WPS)
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)

Company Name	WPS No.	Rev. No.	Date
Authorized by	Date	Supporting PQR(s)	FTT Report

BASE METALS	Specification	Type or Grade	M	Group		Thickness Range As-Welded	Thickness Range w/PWHT
Base Material					Groove Welds		
Welded To					Groove w/FTT		
Backing Material					Partial Pen. Groove Welds		
Other					Fillet Welds		
					Pipe/Tube Diameter Range		

FILLER METALS						Thickness Range	
Process	Spec.	Classification	F-no.	A-no.	Trade Name	As-Welded	w/PWHT
Process 1							
Process 2							
Process 3							
Cons. Insert						□ Required □ Optional □ None	
Flux						□ Required □ Optional □ None	
Sup. Filler						□ Required □ Optional □ None	

JOINT DETAILS	
Groove Type	
Groove Angle	
Root Opening	
Root Face	
Backgouging	
Method	

POSTWELD HEAT TREATMENT	
Temperature	
Time at Temperature	
Other	

JOINT DETAILS (Sketch)

Sketches, production drawings, welding symbols, or written description should show the general arrangement of the parts to be welded. Where applicable, the root details of the weld groove may be specified.

PROCEDURE				
Weld Layer(s) / Pass(es)				
Process				
Type *(Manual., Mechanized, etc.)*				
Preheat Temperature				
Interpass Temperature				
Filler Metal Size				
Position				
Vertical Progression				
Shielding Gas Compos. (GTAW)				
Flow Rate (GTAW)				
Nozzle Size (GTAW)				
Electrical Characteristics	---	---	---	---
Electrode Diameter (GTAW)				
Current Type & Polarity				
Amps				
Volts				
Cold or Hot Wire Feed (GTAW)				
Travel Speed				
Maximum Heat Input				
Technique	---	---	---	---
Stringer or Weave				
Multi or Single Pass (per side)				
Oscillation (GTAW Mech./Auto.)				
Traverse Length				
Traverse Speed				
Dwell Time				
Peening				
Interpass Cleaning				
Other				

Figure G.1—Example of a Welding Procedure Specification

SAMPLE PROCEDURE QUALIFICATION RECORD (PQR)
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)

Company Name	PQR No.	Rev. No.	Date

BASE METALS	Product Form	Specification (Type or Grade)	M-No.	Group-No.	Thick.	Size	Sch.	Dia.
Product Form								
Welded To								
Backing Material								
Other								

JOINT DETAILS	
Groove Type	
Groove Angle	
Root Opening	
Root Face	
Backgouging	
Method	

POSTWELD HEAT TREATMENT	
Temperature	
Time at Temperature	
Other	

JOINT DETAILS (Sketch)

Sketches, welding symbols, or written description should show the actual arrangement of the test coupon welded. Where applicable, the root details of the weld groove may be specified.

PROCEDURE								
Weld Layer(s) / Pass(es)								
Process								
Type *(Manual., Mechanized, etc.)*								
Preheat Temperature								
Interpass Temperature								
Filler Metal (AWS Spec.)								
AWS Classification								
F-number / A-number								
Nominal Composition								
Manufacturer/Trade Name								
Size or Diameter								
Deposited Thickness								
Maximum Pass Thickness								
Position								
Vertical Progression								
Shielding Gas Compos. (GTAW)								
Flow Rate (GTAW)								
Trailing Gas Compos. (GTAW)								
Flow Rate (GTAW)								
Backing Gas Compos. (GTAW)								
Flow Rate (GTAW)								
Electrical Characteristics	---	---	---	---	---	---	---	---
Electrode Diameter (GTAW)								
Current Type & Polarity								
Amps								
Volts								
Cold or Hot Wire Feed (GTAW)								
Travel Speed								
Maximum Heat Input								
Technique	---	---	---	---	---	---	---	---
Cup or Nozzle Size (GTAW)								
Stringer or Weave								
Multi or Single Pass (per side)								
Oscillation (GTAW Mech./Auto.)								
Traverse Length								
Traverse Speed								
Dwell Time								
Peening								
Interpass Cleaning								
Other								

Figure G.2—Example of a Procedure Qualification Record

SAMPLE PQR (Test Results - Page 2)
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)

PQR No. Rev. No.

TESTS

No.	Type of Tests	Clause / Figure(s) Reference	Acceptance Criteria	Result	Remarks

TENSILE TEST DETAILS

Specimen Number	Width	Thickness	Area	Ultimate Tensile Load	Ultimate Unit Stress	Type of Failure and Location

FRACTURE TOUGHNESS TEST DETAILS

Specimen Number	Notch Location	Notch Type	Specimen Size	Test Temperature	Absorbed Energy	Percent Shear	Lateral Expansion	Other

CERTIFICATION

Welder's Name	ID number	Stamp Number

Tests Conducted by	
Laboratory	
Test number	
File number	

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared welded, and tested in accordance with the requirements of AWS D17.1/D17.1M (_____) *Specification for Fusion Welding for Aerospace Applications.*
Year

Title:	Signature
Name:	
Date:	

Figure G.2 (Continued)—Example of a Procedure Qualification Record

SAMPLE PERFORMANCE QUALIFICATION TEST RECORD
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)

Name		OPTIONAL PHOTO ID	Test Date		Rev.
ID Number			Record No.		
Stamp No.			Std. Test No.		
Company			WPS No.		
Division			Qualified To		

BASE METALS	Product Form	Specification (Type or Grade)	M Number	Group Number	Size	Sch.	Thick.	Dia.
Product Form								
Welded To								

VARIABLES	Actual Values		Qualification Limits
Type of weld joint			
Base metal			

	Groove	Fillet	Clad / Hardf.		Groove	Fillet	Clad / Hardf.
Plate/Sheet Thickness							
Pipe/Tube Thickness							
Pipe/Tube Diameter							

Welding Process			
Type *(Manual/Mech./Auto./Semi.)*			
Backing			
AWS Filler Metal Specification			
AWS Classification			
F-Number			
Consumable Insert			
Weld deposit thickness			
Position			
Groove – Sheet & Tube ≥ 1”			
Groove – Tube < 1”			
Fillet – Sheet & Tube			
Clad / Hardfacing			
Vertical Progression			
Backing Gas			
OFW Fuel Gas			
GMAW Transfer Mode			
GTAW welding current/polarity			

TEST RESULTS

Type of Test	Acceptance Criteria	Result	Remarks

CERTIFICATION

Test Conducted by	
Laboratory	
Test number	
File number	

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D17.1/D17.1M (_____) *Specification for Fusion Welding for Aerospace Applications.*

Manufacturer or Contractor _____ Authorized By_____

Date_____

Figure G.3—Example of a Performance Qualification Test Record

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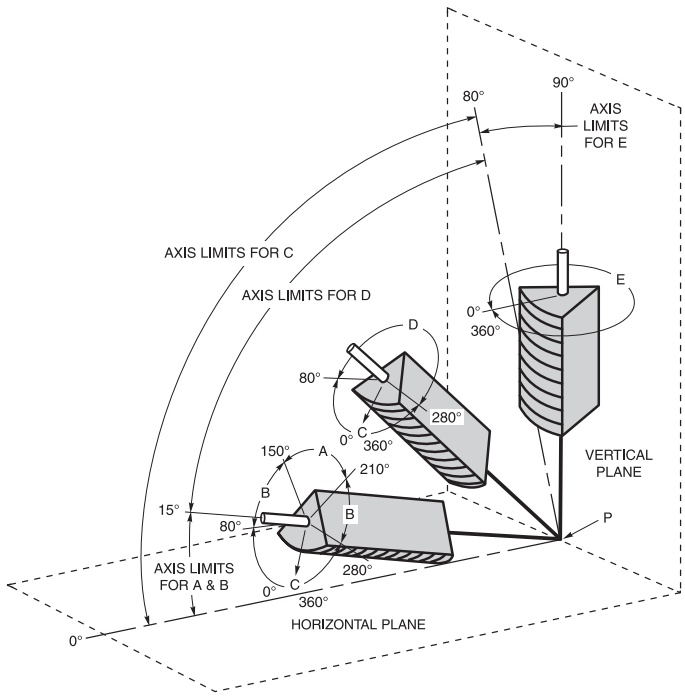
Annex H (Informative)
Qualified Positions for Production Welding

This annex is not part of this standard, but is included for informational purposes only.

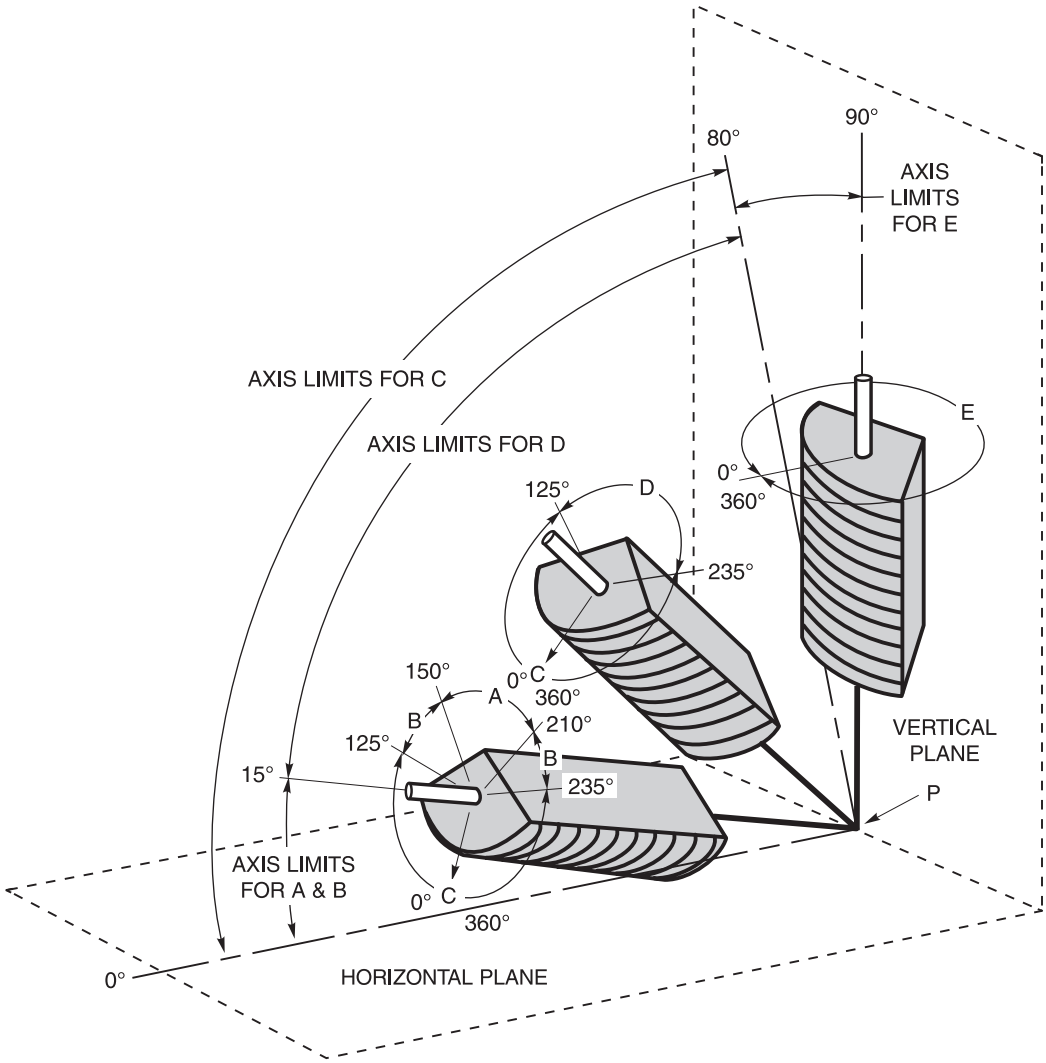


Tabulation of Positions of Groove Welds

Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 360°
Overhead	C	0° to 80°	0° to 80° 280° to 360°
Vertical	D	15° to 80°	80° to 280°
	E	80° to 90°	0° to 360°

Notes:
1. The horizontal reference plane is always taken to lie below the weld under construction.
2. The inclination of the weld axis is measured from the horizontal reference plane toward the vertical reference point.
3. The axis of rotation of the weld face is determined by a line perpendicular to the weld face at its center which passes through the weld axis. The reference position (0°) of rotation of the weld face invariably points in the direction opposite to that in which the weld axis angle increases. When looking at point "P," the angle of rotation of the weld face is measured in a clockwise direction from the reference position (0°).

Figure H.1—Positions of Production Groove Welds



Tabulation of Fillet Welds			
Position	Diagram Reference	Inclination of Axis	Rotation ot Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	125° to 150° 210° to 235°
Overhead	C	0° to 80°	0° to 125° 235° to 360°
Vertical	D E	15° to 80° 80° to 90°	125° to 235° 0° to 360°

Notes:
1. The horizontal reference plane is always taken to lie below the weld under construction.
2. The inclination of the weld axis is measured from the horizontal reference plane toward the vertical reference point.
3. The axis of rotation of the weld face is determined by a line perpendicular to the weld face at its center which passes through the weld axis. The reference position (0°) of rotation of the weld face invariably points in the direction opposite to that in which the weld axis angle increases. When looking at point "P," the angle of rotation of the weld face is measured in a clockwise direction from the reference position (0°).

Figure H.2—Positions of Production Fillet Welds

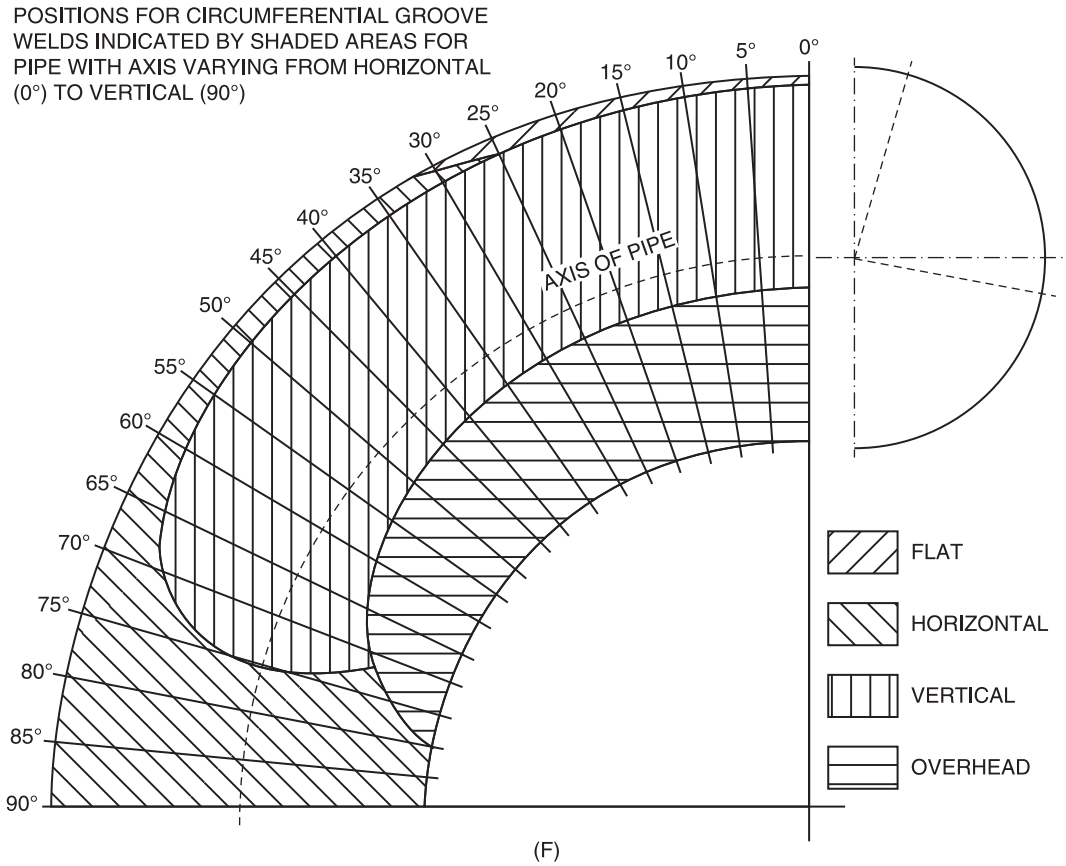


Figure H.3—Production Welding Position Diagram for Groove Welds in Pipe or Tube

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Annex I (Informative)
Common Acronyms Used in this Standard

This annex is not part of this standard but is included for informational purposes only.

HAZ — Heat Affected Zone

MT — Magnetic Testing or magnetic particle examination

MRB—Material Review Board

NDE — Nondestructive Examination

OEM—Original Equipment Manufacturer

PQR — Procedure Qualification Record

PT — Penetrant testing or penetrant examination

PWHT — Post Weld Heat Treatment

RT — Radiographic Testing or radiographic examination

UT—Ultrasonic Testing

WPS — Welding Procedure Specification

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List of AWS Documents on Welding in the Aircraft and Aerospace Industries

Designation	Title
AWS D17.1/D17.1M:2017	*Specification for Fusion Welding for Aerospace Applications*
AWS D17.2/D17.2M:2013	*Specification for Resistance Welding for Aerospace Applications*
AWS D17.3/D17.3M:2016	*Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*

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